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(54) Title: MEMORY SYSTEM

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## (57) Abstract

A memory system (10) having a solid state memory (6) comprising non-volatile individually addressable memory sectors (1) arranged in erasable blocks, and a controller (8) for writing to reading from the sectors, and for sorting the blocks into "erased" and "not erased" blocks. The controller performs logical to physical address translation, and includes a Write Pointer (WP) for pointing to the physical sector address to which data is to be written from a host processor. A Sector Allocation Table (SAT) of logical addresses with respective physical addresses is stored in the memory, and the controller updates the SAT less frequently than sectors are written to with data from the host processor. The memory may be in a single chip, or in a plurality of chips. A novel system for arranging data in the individual sectors (1) is also claimed.

## (57) Abrégé

La présente invention concerne un système de mémoire (10) comportant une mémoire électronique (6) contenant des secteurs de mémoires (1) non volatiles adressables un à un placés dans des blocs effaçables, et un contrôleur (8) assurant les opérations d'écriture et de lecture dans les secteurs, et assurant le classement des blocs en blocs "effacés" et "non effacés". En outre, ce contrôleur assure la conversion d'adresse logique en adresse physique, et applique un pointeur d'écriture (WP) désignant l'adresse secteur physique où les données provenant du processeur hôte doivent être écrites. La mémoire conserve une table d'affectation de secteur (SAT) donnant pour chaque adresse logique une adresse physique correspondante, le contrôleur mettant à jour les SAT moins fréquemment qu'il ne fait d'écriture secteur avec les données provenant du processeur hôte. La mémoire peut être réalisée sous la forme d'un seul microcircuit ou de plusieurs microcircuits. Par ailleurs, cette invention concerne un nouveau système d'organisation des données dans les secteurs (1).

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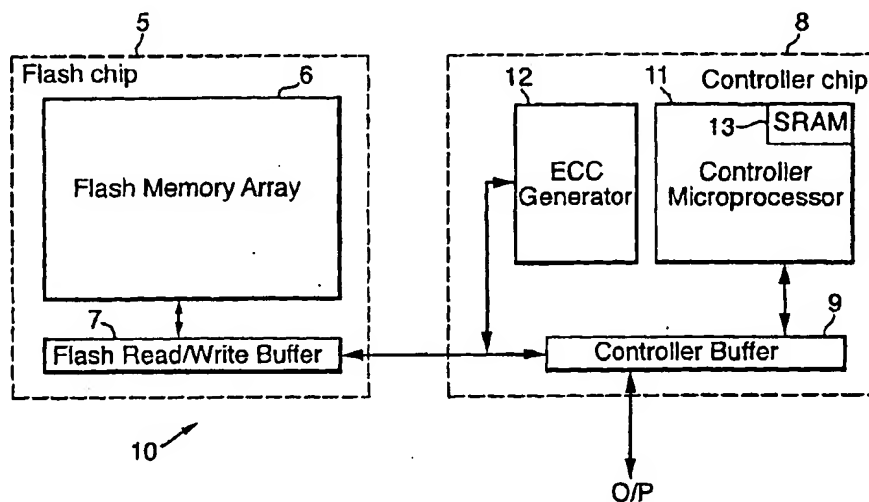
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(54) Title: MEMORY SYSTEM



(57) Abstract

A memory system (10) having a solid state memory (6) comprising non-volatile individually addressable memory sectors (1) arranged in erasable blocks, and a controller (8) for writing to reading from the sectors, and for sorting the blocks into "erased" and "not erased" blocks. The controller performs logical to physical address translation, and includes a Write Pointer (WP) for pointing to the physical sector address to which data is to be written from a host processor. A Sector Allocation Table (SAT) of logical addresses with respective physical addresses is stored in the memory, and the controller updates the SAT less frequently than sectors are written to with data from the host processor. The memory may be in a single chip, or in a plurality of chips. A novel system for arranging data in the individual sectors (1) is also claimed.

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## Description

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**MEMORY SYSTEM**

5 The present invention relates to a solid state memory system  
for data storage and retrieval, and to a memory controller for  
controlling access to a non-volatile memory of a solid state  
10 memory system. In particular, the invention relates to FLASH  
memory systems and controllers for FLASH memories.

15 FLASH EEPROM (electrically erasable programmable read only  
memory) devices are commonly used in the electronics industry  
10 for non-volatile data storage. Various types of FLASH memory  
devices exist, including devices based on NAND type memory  
20 cells, AND type memory cells, or NOR type memory cells. Such  
devices may have different types of interfaces to the host  
processor system(s) for which they are designed to interface,  
15 for example they may use a serial access type interface (as  
commonly used in many NAND and AND type devices) or a random  
access type interface (as used in some NOR type devices). The  
present invention is intended to be applicable, in appropriate  
30 forms, to at least some and preferably all of these different  
20 types of memory devices.

35 It is known to use solid state memory systems to try to  
emulate magnetic disc storage devices in computer systems. It  
is an aim of the industry to try to increase the speed of  
25 operation of solid state memory systems so as to better  
emulate magnetic disc storage.  
40

According to a first aspect of the present invention we  
provide a memory system for connection to a host processor,  
45 the system comprising:  
a solid state memory having non-volatile memory sectors which  
are individually addressable and which are arranged in  
erasable blocks of sectors, each said sector having a physical  
50 address defining its physical position in the memory;

5 and a controller for writing data structures to and reading  
data structures from the memory, and for sorting the blocks of  
sectors into blocks which are treated as erased and blocks  
10 which are treated as not erased; wherein the controller  
5 includes:

means for translating logical addresses received from the host  
processor to physical addresses of said memory sectors in the  
15 memory;

a write pointer (hereinafter referred to as the Write Pointer  
10 (WP)) for pointing to the physical address of a sector to  
which data is to be written to from the host processor, said  
20 Write Pointer (WP) being controlled by the controller to move  
in a predetermined order through the physical addresses of the  
memory sectors of any block which is treated as erased and,  
25 when the block has been filled, to move to another of the  
erased blocks;

wherein the controller is configured so that, when a sector  
write command is received from the host processor, the  
30 controller translates a logical address received from the host  
20 processor to a physical address to which data is written by  
allocating for said logical address that physical address to  
which said Write Pointer (WP) is currently pointing; and  
35 wherein the controller is configured to compile a table of  
logical addresses with respective physical addresses which  
25 have been allocated therefor by the controller (this table  
being hereinafter referred to as the Sector Allocation Table  
40 or SAT), and wherein the controller updates the SAT less  
frequently than memory sectors are written to with data from  
the host processor.

45 30  
By not updating the SAT every time data from the host  
processor is written to a sector in the memory, but instead  
50 updating the SAT on a less frequent basis, the present  
invention thus provides very high speed operation of solid

5 state memory, for example FLASH memory, thereby enabling good emulation of magnetic disk memory.

10 The physical sector addresses in the SAT are preferably  
5 ordered by logical sector address, whereby the Nth SAT entry contains the physical address of a sector to which data having logical address N has been written. When a sector read command  
15 is received from the host processor, the controller may look up a logical sector address received from the host processor  
10 in the SAT in order to obtain the physical sector address which the controller previously allocated to said logical  
20 sector address. The SAT is preferably stored in one or more of said blocks of memory sectors in the solid state memory, each block which contains any portion of the SAT hereinafter being  
25 referred to as a SAT block. Preferably the SAT is updated by rewriting one or more blocks of the SAT. By updating a whole block of SAT sectors at a time this significantly speeds up operation of the memory system.

30 There may be provided at least one block of sectors (hereinafter referred to as the Additional SAT Block (ASB)), containing modified versions of individual sectors of a said  
35 SAT block. Each sector in a said ASB block preferably contains the physical address of the sector of the SAT block which it  
25 updates, and the modified version of the said SAT sector. The purpose of an ASB is to cache individually in solid state  
40 memory modified sectors of the SAT so as to reduce the number of SAT block rewrites. When all the sectors in a said ASB block are written to with modified versions of SAT sector(s),  
45 30 the respective SAT block is rewritten so as to include all the modified versions in the ASB block and the ASB block is erased.

50 It will be appreciated that in the memory system of the  
35 present invention the physical address which is allocated to

any given logical address received from the host processor is not dependent on the logical address itself. The controller merely allocates the physical sector address to which the Write Pointer is currently pointing.

5

As described above, the controller fills one said block which is treated as erased before moving the Write Pointer (WP) on to another block. The controller may conveniently be configured to move the Write Pointer (WP) in a predetermined order through the blocks which are treated as erased.

The controller may conveniently control the Write Pointer (WP) so as to move sequentially, in ascending numerical order of physical address, through the erased blocks, as each block is filled with data written thereto. The control of the Write Pointer (WP) may be cyclic in the sense that once the sectors in the highest block, according to physical address order, have been filled with data the WP is controlled by the controller to wrap around to the block of sectors having the numerically lowest physical addresses out of all the blocks currently being treated by the controller as erased.

The controller may, alternatively, use another predetermined order for writing data to the memory sectors. For example, the controller may control the Write Pointer (WP) to move sequentially in descending numerical order, according to physical address, through the blocks which are treated as erased. Another possibility would be to move in non-sequential order through the physical sector addresses. For example, the WP may move in descending numerical address order through the physical sector addresses in each block which is treated as erased, and move from block to block in some predetermined order such as, for example, in ascending numerical order according to the physical address of the first sector in each said block.



5 It will be appreciated that many other predetermined orders  
are possible for writing data to the sectors in the blocks  
which are treated as erased. Furthermore, the controller could  
10 use the erased blocks in any other order which need not be  
predetermined, or which may be only partially predetermined.  
Although generally not preferred, the erased blocks could even  
15 be used in a random order.

10 The memory sectors in each said block of sectors are  
preferably erasable together as a unit. The sectors may also  
20 be individually erasable (for example where the solid state  
memory is AND type memory). The controller is preferably  
configured to control erase operations on the memory so as to  
25 only erase whole blocks of memory sectors. A block of sectors  
will be treated by the controller as an erased block if all  
the memory sectors therein are erased sectors. If a block  
contains one or more bad (i.e. defective) sectors, the  
30 controller may define the whole block as being bad and treat  
that block as a not erased block, whereby no data will be  
written thereto. Alternatively, if a block contains one or  
more bad sectors the controller may treat that block as an  
35 erased block whereby the controller may still use good sectors  
in the block to store data. In the latter case, though, the  
25 memory system preferably includes a table identifying bad  
sectors and the controller is configured to check whether the  
40 next sector address to which the Write Pointer (WP) is to be  
moved is the address of a bad sector and, if it is the address  
of a bad sector, to control the Write Pointer to skip this bad  
45 sector and move to the next sector address according to the  
predetermined order in which the sectors are to be written to.

50 For the avoidance of doubt, any block which contains any good  
(i.e. not defective) sectors which have already been written  
35 to will be treated by the controller as a not erased block.

5 Furthermore, it is intended that the term "erased" sector  
covers not only a sector which has been erased, but also  
covers a sector which has never yet been written to, and so  
10 has not yet ever been erased. Thus, a block of sectors which  
5 have never yet been written to is treated by the controller as  
an erased block.

15 Each block of sectors preferably has a physical block address  
defining its physical position in the memory. The physical  
10 address of each said memory sector will preferably include the  
physical block address of the block in which it is located.  
20 The controller may advantageously be configured to compile a  
list of the physical block addresses of at least some of the  
blocks of sectors being treated as erased, which may be used  
25 by the controller in order to quickly identify the next block  
of sectors to be written to. This list of addresses of erased  
blocks is preferably stored by the controller in a temporary  
30 memory which may be provided in the memory system, which  
temporary memory may conveniently be an SRAM in a  
20 microprocessor of the controller, and may be created from  
information already stored in the solid state memory by the  
controller identifying the erased state of each block of  
35 sectors. (This information will preferably be held in the form  
of a bitmap in the solid state memory, in which each block is  
25 recorded as an erased block or a not erased block.)

40 The controller is conveniently configured so that, when a  
sector write command is received by the controller from the  
host processor which command renders obsolete data previously  
45 written to another sector, the controller stores in a  
temporary memory the address of the sector containing the now  
obsolete data. This temporary memory may conveniently be SRAM  
50 or DRAM provided in a microprocessor of the controller. If a  
sector delete command, generated by a user, is received from  
35 the host processor by the controller, the controller

5 preferably marks as obsolete the sector to be deleted (without  
physically erasing the sector). The controller may allow only  
one block at any time, hereinafter referred to as the Current  
10 Obsolete Block (COB), to contain one or more sectors  
5 containing obsolete data which was written by the Write  
Pointer (WP), and when all the sectors in the COB contain  
obsolete data, the COB is immediately erased. This is a  
15 particularly suitable scheme for the case where the Write  
Pointer (WP) moves sequentially through the memory sector  
20 addresses in each block which is treated as erased before  
moving on to the next block. In such a scheme, a series of  
obsolete sectors to be deleted (which may, for example,  
contain part of a user data file which has been rewritten)  
will in most cases all be in the same block. When a series of  
25 sectors are rewritten in a different order to that in which  
they were previously written, this may create obsolete sectors  
in more than one block. Where a sector in a block other than  
the COB is to contain obsolete data, the controller preferably  
30 relocates any data in valid (not obsolete) sectors in the COB  
20 to another block, which may be the block to which the Write  
Pointer (WP) is currently pointing, and then erases the COB.  
Said sector in the block other than the COB is then marked as  
35 obsolete and this other block is now the COB. Rather than  
writing the relocated data to the current location of the  
25 Write Pointer, the memory system may include a second write  
pointer, hereinafter referred to as the Relocation Pointer  
40 (RP), for pointing to the physical address of the sector to  
which such relocated data is to be written, the Relocation  
Pointer (RP) always being in a different block of sectors to  
45 the Write Pointer (WP). This has the advantage of preventing  
relocated data from being intermingled with data structures  
directly ordered to be written by the host processor i.e.  
50 written by the Write Pointer (WP).

55

5 Generally, only two types of data are written to the solid  
state memory from the host processor. These are file data and  
system data. To further reduce the number of reallocations and  
10 erasures, the memory system may further include a third write  
5 pointer, hereinafter referred to as the System Write Pointer  
(SWP), which points to the physical address of the sector to  
which system data is to be written from the host, the SWP  
15 always being in a different block to the Write Pointer (WP)  
(and in a different block to the Relocation Pointer, if there  
10 is one). System data will preferably be identified during  
initialisation of the system and will be updated as necessary  
20 during operation.

Where both a write pointer (WP) and a system write pointer  
25 15 (SWP) are provided, file data will in this case always be  
written to the addresses pointed to by the Write Pointer (WP).  
Both the Relocation Pointer (RP) and System Write Pointer  
(SWP) are preferably controlled to move through the physical  
30 addresses of the memory sectors in said blocks which are  
20 treated as erased in a similar manner to the Write Pointer  
(WP). Thus, when all the (good) sectors in a said block have  
been filled with relocated data or system data, the respective  
35 one of the Relocation Pointer (RP) and the System Write  
Pointer (SWP) moves on to the next address defined by the  
25 controller to be used from the physical addresses of all the  
sectors in the blocks treated as erased.  
40

Where a System Write Pointer (SWP) is provided, the controller  
will preferably allow at least two blocks which contain one or  
45 30 more obsolete sectors to exist at any time, one being said COB  
and the other being a Current Obsolete System Block (COSB)  
containing one or more obsolete system data sectors. If any  
50 system data sectors need to be relocated in order to allow the  
COSB to be erased, the relocated system data is preferably

5 sent to the address to which the System Write Pointer (SWP) is currently pointing.

10 In fact, there may temporarily exist more than two blocks (the  
5 COB and COSB) containing obsolete data at any one time. It is possible that when the COB, for example, needs to be erased (obsolete data has just been created in another block) one of  
15 the write pointers may be pointing thereto i.e. the WP is still writing to the block which is currently the COB. Where  
10 this is the case the controller preferably proceeds with creating the new COB but postpones the erasure of the old COB  
20 (which is hereinafter treated as the Pending Obsolete Block (POB)) until all erased sectors in the POB have been filled and the write pointer moves on to the next erased block to be  
25 used, as defined by the controller. At this time any valid (not obsolete) data in the POB is relocated and the POB is erased.

30 In addition to writing data structures to the memory from the  
20 host processor, the controller may also generate and write to the memory data designated as control information. The  
35 controller preferably writes such control information in separate ones of the blocks of memory sectors to those in which data structures received from the host processor are  
25 written. Blocks for storing such control information, hereinafter referred to as Control Blocks (CBs), will be  
40 updated periodically by the controller and will be accessed during initialisation, and occasionally during operation, of the memory system.

45 30 The controller preferably stores in a temporary memory (which may be a RAM provided in the memory system or which may  
50 conveniently be an embedded SRAM or DRAM in a microprocessor of the controller) a list of logical sector addresses for data  
35 structures which have been written by the Write Pointer (WP)

5 since the SAT was last updated. This list stored in the SRAM  
is hereinafter referred to as the ~~Write Sector List (WSL)~~. The  
logical addresses in the WSL are advantageously stored in the  
10 order in which they were written to the non-volatile sectors  
5 in the memory. Conveniently, for a group of consecutively  
written sectors, the WSL entry may therefore be written as the  
first sector logical address and the sector group length i.e.  
15 the number of sectors written. Each said sector group is  
defined so as not to span more than one block of sectors.

10

20 The controller advantageously also stores in said temporary  
memory the order in which blocks have been used by the Write  
Pointer (WP) for writing data since the last update of the  
SAT. This is stored in the form of a list of block addresses  
25 of the blocks in which the updated sectors whose addresses are  
held in the WSL are located. This list of block addresses is  
hereinafter referred to as the Write Block List (WBL). It will  
be appreciated that since the memory system, by virtue of the  
30 WSL and WBL, contains knowledge of the location in physical  
20 memory which was allocated for the first logical address in  
said group of consecutively written sectors, the controller  
can thus always access the correct physical sector for each  
35 logical sector address in a said group of consecutively  
written sectors written since the last SAT update, using the  
25 WSL and WBL. The WSL will preferably have a predetermined size  
and once the WSL is full one or more SAT blocks (and/or ASBs)  
40 may be updated and the WSL and WBL are emptied.

45 Preferably, the starting physical sector address, and the  
30 links between blocks containing sectors to which data has been  
written by the controller since the last SAT update, are also  
stored in a Control Block of the solid state memory. By  
50 storing the logical sector address for the user data stored in  
each sector in the sector itself, for example in a header  
35 field provided in the sector, the WSL and WBL can therefore

5 easily be recreated following any removal and restoration of  
power to the system by scanning through the solid state  
memory, reading the logical addresses in the sectors written  
10 to since the last update of the SAT, until reaching a block  
5 which is not full. This is the block which contained the Write  
Pointer (WP) before removal or loss of power. This provides  
high data security in the event of unexpected power removal  
15 from the memory system.

10 Where a Relocation Pointer and a System Write Pointer are  
included in the memory system, the controller preferably also  
20 stores in said temporary memory (e.g. SRAM or DRAM in the  
controller microprocessor) similar lists of logical sector  
addresses corresponding to sectors in the memory to which  
25 relocated data or system data has been written to  
respectively, which lists are hereinafter referred to as the  
Relocation Sector List (RSL) and Write System Sector List  
(WSSL) respectively. The controller may also store in said  
30 temporary memory corresponding lists of the order of blocks  
20 which have been used by the RP and the SWP, similar to the  
Write Block List, and these two lists will hereinafter be  
referred to as the Relocation Block List (RBL) and the Write  
35 System Block List (WSBL). Moreover, the starting physical  
sector address, and the links between blocks containing  
25 sectors to which relocated data or system data has been  
written since the last SAT update may also be stored in at  
40 least one said Control Block (CBs) of the solid state memory  
whereby the RSL and WSSL can be recreated following any  
removal and restoration of power to the host processor by  
45 30 simply scanning the memory and reading the logical addresses  
in the sectors written to by the RP and SWP respectively,  
since the last update of the SAT.

50 Each said sector in any of the above-described embodiments may  
35 consist of a single "page" of memory i.e. one row of memory

5 cells in a said block of memory sectors. However the invention  
is not limited exclusively to such a sector format and in some  
cases (for example when using random access NOR type memory)  
10 each said sector may be less than, or greater than, one page.  
5 Moreover, in the latter case not all said sectors need  
necessarily be of the same size. For example, a data  
organisation scheme such as that described in our earlier  
15 International Patent Application No. PCT/GB99/00188 could be  
used by the controller to form sectors of appropriate sizes so  
10 as to avoid individual defects (of sub-sector size) which may  
be present in the solid state memory.

20 Each sector is, as aforesaid, individually addressable. Each  
sector may comprise a plurality of sector portions which are  
25 also each individually addressable and the controller may  
write to, and read from, each sector portion individually. It  
will be appreciated that the smallest possible sector portion  
size is the minimum addressable unit of the memory. In NOR  
30 type memory, for example, the minimum addressable unit of  
20 memory is commonly 1 byte.

35 The controller preferably writes data to, and reads data from,  
the memory sectors in uniformly sized data segments. Where all  
the memory sectors are the same size, each said data segment  
25 is preferably equal in size to the size of a said memory  
sector. Each data segment may comprise data structures from  
40 the host processor (e.g. file or system data) and/or data  
generated by the controller.

45 30 Where the solid state memory is based on NAND type devices,  
the controller preferably stores in said one or more Control  
Blocks a list of the block addresses of blocks in the non-  
volatile memory containing bad sectors (hereinafter referred  
50 to as the Bad Block List (BBL)), and the controller treats  
35 each such block as a "not erased" block, so that it will not



5 appear in the list of erased blocks which may be stored in temporary memory, and the controller will not write any data to that block.

10 5 Where the memory is based on AND type devices, the controller preferably stores in said one or more Control Blocks (CBs) a list of addresses of any bad sectors, and the controller  
15 controls the said write pointer(s) to use the good sectors in any block containing at least one bad sector, and to skip any  
20 bad sectors. It will be appreciated that in the latter case where a block containing one or more bad sectors is to be  
erased the good (i.e. non-defective) sectors in the block are  
erased individually during a block erase operation.

25 15 The controller advantageously also stores in said one or more Control Blocks a list of the block addresses of all SAT  
blocks. This list is preferably in the form of a plurality of  
list portions, each said portion being hereinafter referred to  
30 as a Table Block List (TBL), and each said portion containing  
20 the block addresses of a group of logically contiguous SAT  
blocks and any corresponding ASBs.

35 The controller preferably stores the block addresses of said one or more Control Blocks in a dedicated block of the memory  
25 hereinafter referred to as the Boot Block (BB). Other  
important information required for data security may also be  
40 stored in the Boot Block, for example the list of bad blocks (or bad sectors). Preferably, the first block of sectors in the memory which does not contain any bad sectors is  
45 30 designated as the Boot Block (BB).

50 Preferably, the controller will only use blocks containing all good sectors as SAT blocks, Control Blocks, ASBs or BBs.

5 A cache may be provided in temporary memory (for example RAM  
in the memory system, such as SRAM or DRAM in the controller  
microprocessor), in which the controller stores a group of  
10 contiguous SAT entries including the SAT entry most recently  
5 accessed from the SAT (by the controller). This further  
improves address translation speed. Further increase in speed  
of address translation may be achieved by creating in said  
15 temporary memory a list of physical addresses of all ASBs and  
the SAT blocks with which they are associated (hereinafter  
10 referred to as the ASB List or ASBL) which is updated each  
time a SAT sector write operation is performed. Similarly, the  
20 positions of the TBLs in the Control Block(s) may also be  
stored in said temporary memory so as to allow even faster  
logical-to-physical sector address translation.

25 15  
The solid state memory may comprise a single memory array in  
the form of a single memory chip, or may comprise a plurality  
of memory arrays in the form of a plurality of memory chips.  
30 Where the memory comprises a plurality of chips, the  
20 controller advantageously forms the memory sectors in the  
plurality of memory chips into a multiplicity of virtual  
blocks, each said virtual block comprising one erasable block  
35 of memory sectors from each said memory chip, and the  
controller preferably sorts said virtual blocks into ones  
25 which are treated as erased and ones which are treated as not  
erased. The controller preferably compiles a list of the  
40 virtual blocks treated as erased and stores this in temporary  
memory in the memory system, which may be SRAM in a  
microprocessor of the controller. The controller preferably  
45 30 controls the Write Pointer (WP) (and the RP and SWP, where  
provided) to move from one chip to another for each  
consecutive sector write operation, starting at one sector in  
one erasable block of the virtual block and moving  
50 consecutively to one sector in each of the other erasable  
35 blocks in the virtual block until one sector has been written

5 in each erasable block of the virtual block, and then moving  
back to the chip in which the first sector was written and  
proceeding in a similar manner to fill another one sector in  
10 each erasable block of the virtual block, and so on until the  
5 virtual block is full of data. The Write Pointer (WP) then  
moves on to the next virtual block in said list of virtual  
blocks being treated as erased, and fills this next virtual  
15 block in a similar manner. The controller is preferably  
configured so that for every n contiguous sector write  
10 operations the controller executes, where n is less than or  
equal to the number of solid state memory chips in the memory  
20 system, the controller writes substantially concurrently to  
one sector in each of n of the chips. The controller  
preferably carries out erasure of any said virtual block by  
25 15 concurrently erasing all the erasable blocks in the virtual  
block.

30 It will be appreciated that the controller of the memory  
system may be substantially implemented in circuitry as a  
20 controller device, but will preferably be implemented, at  
least in part, as firmware held in the memory of a controller  
device. The controller may be integrally formed on the same  
35 chip (or one of the same chips) as the solid state memory.

25 According to a second aspect of the invention we provide a  
memory system for connection to a host processor, the memory  
40 system comprising:  
a solid state memory comprising a plurality of solid state  
memory chips each having non-volatile memory sectors which are  
45 30 individually addressable and which are arranged in erasable  
blocks of sectors, each said sector having a physical address  
defining its physical position in the memory;  
and a controller for writing data structures to and reading  
50 data structures from the memory, wherein:

5 the controller forms the erasable blocks into virtual blocks,  
each said virtual block comprising an erasable block from each  
of the memory chips, and the controller sorts the virtual  
10 blocks into ones which are treated as erased and ones which  
5 are treated as not erased, and the controller fills one  
virtual block with data prior to moving on to the next virtual  
block to be filled, and each virtual block is filled by  
15 writing to the memory sectors thereof in a repeating sequence  
in which the controller writes to one memory sector in each of  
10 the erasable blocks of the virtual block one after another  
whereby consecutively written sectors are in different chips.  
20

Preferably, the controller is configured so that for every n  
contiguous sector write operations the controller executes for  
25 15 a multiple sector write command received from the host  
processor, where n is less than or equal to the number of  
solid state memory chips in the memory system, the controller  
writes substantially concurrently to one sector in each of the  
30 n of the chips.

20

According to a third aspect of the invention we provide a  
35 controller for writing data structures to and reading data  
structures from a solid state memory having non-volatile  
memory sectors which are individually addressable and which  
25 are arranged in erasable blocks of sectors, each said sector  
40 having a physical address defining its physical position in  
the memory, wherein the controller includes:  
means for translating logical addresses received from a host  
processor of a memory system in which the controller is used  
45 30 to physical addresses of said memory sectors in the memory,  
and for sorting the blocks of sectors into blocks which are  
treated as erased and blocks which are treated as not erased;  
50 and a Write Pointer (WP) for pointing to the physical address  
of a sector to which is to be written to from the host  
35 processor, said Write Pointer (WP) being controlled by the

5 controller to move in a predetermined order through the  
physical addresses of the memory sectors in any block which is  
treated as erased and, when the block has been filled, to move  
10 to another of the erased blocks;  
5 and wherein, when a sector write command is received by the  
controller from the host processor, the controller translates  
a logical sector address received from the host processor to a  
15 physical address to which data is written by allocating for  
said logical address that physical address to which said Write  
10 Pointer (WP) is currently pointing;  
and wherein the controller is configured to compile a table  
20 (the SAT) of logical addresses with respective physical  
addresses which have been allocated therefor by the  
controller, and to update the SAT less frequently than memory  
25 15 sectors are written to with data from the host processor.

According to a fourth aspect of the invention we provide a  
method of controlling reading and writing of data structures  
30 to and from a solid state memory having non-volatile memory  
20 sectors which are individually addressable and which are  
arranged in erasable blocks of sectors, each said sector  
having a physical address defining its physical position in  
35 the memory, the method comprising the steps of:  
sorting the blocks of sectors into blocks which are treated as  
25 erased and blocks which are treated as not erased;  
40 providing a Write Pointer (WP) for pointing to the physical  
address of a sector which is to be written to, and controlling  
said at least one Write Pointer (WP) so as to move in a  
predetermined order through the physical addresses of the  
45 30 memory sectors of any block which is treated as erased and,  
when the block has been filled, to move to another of the  
erased blocks;  
and, when a sector write command is received from the host  
50 processor, translating a logical address received from the  
35 host processor to a physical address to which data is written

5 by allocating for said logical address that physical address  
to which said Write Pointer (WP) is currently pointing;  
storing in non-volatile solid state memory a table (the SAT)  
10 of logical addresses with respective physical addresses which  
5 have been allocated therefor by the controller;  
and updating the SAT less frequently than memory sectors are  
written to with data from the host processor.

15 Preferred embodiments of the invention will now be described  
10 by way of example only and with reference to the accompanying  
drawings in which:

20 Fig.1 is a schematic illustration of one block of sectors in a  
NAND type FLASH memory, showing three sectors therein;

25 Fig.2 is a block diagram of a memory system comprising a FLASH  
15 chip and a controller chip;

Fig.3 is a schematic illustration of one page of data in a  
NAND or AND type FLASH memory;

30 Fig.4 shows the structure of a Header field of the page of  
Fig.3;

20 Fig.5 illustrates the format of a physical address (PA) of a  
page;

Fig.6 illustrates a Control Block (CB) entry;

35 Fig.7 illustrates one entry in a Table Block List (TBL);

Fig.8 shows the format of a MAP entry;

25 Fig.9 shows the format of an entry in the ASB List (ASBL);

40 Fig.10 illustrates the format of a Current Obsolete Block  
(COB) Structure;

Fig.11 is a table illustrating the order in which sectors are  
written to in a virtual block of a multiple FLASH chip memory  
45 30 system according to one embodiment of the invention;

Fig.12 shows the format of a Virtual Address (VA);

Fig.13 shows how the PA is obtained from the VA;

50 Fig.14 illustrates the timing of operations during a multiple  
sector write to a multiple FLASH chip memory system according  
35 to the invention;

Fig.15 is a block diagram of a controller chip;

Fig.16 is a table showing allocated memory capacity for a memory system of the invention;

Fig.17 is a flow diagram showing an Address Translation process;

Fig.18 is a flow diagram of the steps carried out at box 58 of Fig.17;

Fig.19 is a block diagram of a multiple FLASH chip memory system comprising four FLASH chips and a controller chip;

Fig.20 is a flow diagram of the steps carried out at box 56 of Fig.17;

Fig.21 is a flow diagram of the steps carried out at box 44 of Fig.17;

Fig.22 is a flow diagram of a sector read operation;

Fig.23 is a flow diagram of a sector write operation;

Fig.24 is a flow diagram of the steps carried out at box 161 of Fig.23;

Fig.25 is a flow diagram of the steps carried out at box 207 of Fig.24;

Fig.26 is a flow diagram of the steps carried out at box 160 227 of Fig.23;

Fig.27 is a flow diagram of a sector delete operation;

Fig.28 illustrates the physical partitioning of a page in NAND or AND type FLASH memory;;

Fig.29 is an illustration of an alternative way of arranging the data in the FLASH page of Fig.28;

Fig.30 is an illustration of a yet further way of arranging the data in the FLASH page of Fig.28;

Figs.31(a) illustrates data in a buffer memory of the controller prior to a sector write operation;

Fig.31(b) illustrates data in a FLASH page after completion of a write operation, where the data is arranged according to the embodiment of Fig.30;

Fig.32 is a table of controller commands used to transfer the data from the controller buffer to the FLASH memory during the write operation of Figs.31(a) and (b);

Fig.33 illustrates data in a buffer memory of the controller 5 after a read operation;

Fig.34 is a table of of controller commands used to transfer the data from the FLASH memory to the controller buffer during the read operation of Fig.33; and

Fig.35 is a schematic block diagram of an erasable block of 10 sectors in NOR type FLASH memory, showing three sectors therein.

Fig.1 illustrates schematically the physical page structure in 15 one block 4 of a FLASH memory array based on NAND type memory cells. Fig. 1 shows three pages 1, 2, 3 in the block 4. The page 1 in physical terms comprises one row of memory cells in a block of memory, the memory being partitioned into many such 30 blocks each comprising a multiplicity of rows of memory cells (i.e. a multiplicity of pages). Each page 1, 2, 3 is treated as one sector of physical memory space in the FLASH memory system which will be described and is 528 Bytes wide. Each 35 page 1 in the memory is individually addressable (for read/write and delete operations), and the pages are erasable 25 in blocks. We will now describe a memory system incorporating such a memory array. We will later additionally describe memory systems based on AND or NOR type FLASH memory.

Fig.2 shows a memory system 10 incorporating a FLASH memory 45 chip 5 and a controller chip 8. The FLASH memory chip 5 comprises a FLASH memory array 6 and a read/write buffer 7 interfaced to a controller buffer 9 in the controller chip 8. The controller chip 8 further includes a controller 50 microprocessor 11 and an Error Correction Code (ECC) generator 35 and checker 12. The controller buffer 9 interfaces to a host



5 computer processor (not shown) connected to the memory system  
10 via an output O/P of the controller chip 8. The controller  
chip 8 (hereinafter referred to as the "controller"), controls  
the reading and writing of data structures to and from the  
10 memory array 6. The host processor 2 connected to the memory  
system 10 sends read and write commands to the controller 8.  
Data can be accessed by the host in 512 Byte portions or "host  
15 data sectors", each of which has a logical sector address  
(LA). The controller 8 receives an LA from the host processor  
10 and translates this to a physical address as will be described  
hereinbelow. In the present case (NAND type memory), each  
20 physical address (PA) defines the physical position of a page  
1 of the FLASH memory in the array 6. Each LA is in the form  
of one 24 bit field. Accessing a PA using an LA is referred  
25 to as address translation and is commonly the most frequent  
operation needed on every read/write access. The controller 8  
writes data to the memory array 6 in data segments, each  
segment being 528 Bytes wide. For each 512 Bytes of data  
30 received from the host (e.g. user file or system data) the  
20 controller generates 16 Bytes of data comprising a 4 Byte  
Header generated by the microprocessor 11 and a 12 Byte ECC  
produced by the ECC generator and checker 12. The controller  
35 organises this into a 528 Byte data segment which is written  
to one page of the memory array 6, via the FLASH buffer 7.  
25 The logical address (LA) of a host data sector is stored in  
the 4 Byte Header in the FLASH Sector 1 in which that host  
40 data sector is written. On a read operation the data stored in  
the relevant sector of the FLASH memory array is read from  
array 6, via the FLASH read/write buffer 7, into the  
45 controller buffer 9 (and concurrently to the ECC generator and  
checker to check for errors in the data), and the controller  
reads the 4-byte header to check that the stored LA matches  
50 the LA requested by the host computer, prior to allowing the  
host computer to read the data from the controller buffer 9.

5 The Controller 8 manages the physical location of data written  
to the memory 6 on an individual sector basis. As will be  
later described in further detail, the controller stores in  
10 the memory 6 a BitMap (MAP) of erased blocks and compiles in  
5 SRAM in the microprocessor 11 a list (the Next Erased Block  
(NEB) list) of at least some erased blocks, ordered in  
ascending order of block physical addresses, which erased  
15 blocks are to be used for writing to. The physical page  
location at which a host data sector is written does not  
10 depend on the logical address received from the host. Each  
Host Data sector is written at an address defined by a cyclic  
20 write pointer. Special write pointers are used for different  
types of write operations; host file data writes are performed  
at an address pointed to by the Data Write Pointer (WP), host  
25 system data writes at an address pointed to by the System  
Write Pointer (SWP). The Relocation Pointer (RP) is used for  
writing sectors which were not directly ordered by a host.  
Each of these write pointers has an identical behaviour: each  
30 pointer moves sequentially through the pages of a block, then  
20 moves to the first page of the next erased block in the Next  
Erased Block (NEB) list. Blocks containing files which are  
not erased are treated as "not erased" blocks and are skipped  
35 when a pointer moves from one block to another (and are never  
included in the NEB).

25

#### 40 Sector Relocation Algorithm

When a block 4 of sectors is to be erased, so as to recover  
sector space containing obsolete data, sectors must be  
relocated from a block containing a combination of valid and  
45 obsolete sectors to allow the block to be erased. In  
principle, the controller 8 allows only one block  
corresponding to a specific write pointer to contain obsolete  
50 data sectors at any time. When a sector to be written by the  
host would produce an obsolete sector in a second block, the

5 existing block must first be erased, after relocation of valid sectors, if necessary.

10 Therefore, numerous erasures and extensive relocations of  
5 sectors are unavoidable when a majority of blocks are to  
contain both valid and obsolete sectors. This occurs only  
when a sequence of sectors written by a host as a part of a  
15 file differs from the sequence in which they had previously  
been written. This is not the normal case in most  
20 applications. However, even in case of normal file write  
operation, relocation of non-related data must be performed  
from blocks containing a "head" and "tail" of a file. There  
is a high probability that relocation of system data  
intermingled with "other file" data will cause additional  
25 erasure of another block and this will produce more  
relocations from this block.

30 To reduce the total number of relocations and erasures system  
data is therefore specifically identified and is always  
20 written or relocated at the address of the System Write  
Pointer (SWP). Information about system data is obtained  
during initialisation process and is stored in the  
35 microprocessor SRAM 13. It will be generally understood that a  
data file is written to the FLASH memory by a file system in  
25 the host computer processor. File data is partitioned into  
clusters by the file system, where each cluster is a group of  
40 contiguous host data sectors of (typically) 512Bytes. The file  
system maintains tables and data structures relating to the  
attributes of the files stored in the memory and the locations  
45 30 of the clusters which form each file. These tables and  
structures are stored in the FLASH memory (as system data) and  
are updated by the file system whenever file data is written.  
When file data is written to the memory it is accompanied by  
50 system data (e.g. for Directory and File Allocation Tables)  
35 which relate to the file. System data written in the memory

5 commonly includes BIOS Parameter configuration information,  
one or two copies of the File Allocation Table (FAT) in which  
each entry relates to a specific cluster, the Root Directory,  
10 and Subdirectory information. The controller is configured to  
5 recognise an operation to write a host system data sector,  
thereby enabling it to treat this host data sector differently  
to a host data sector of file data. A number of methods may be  
15 used either singly or together to recognise system sector  
writes, as follows:

- 10 1. System data is written with single sector write commands,  
whilst file data may be written with multiple sector write  
20 commands.
2. All sectors with LAs below the last sector address in the  
file system Root Directory are system sectors. This address  
25 can be determined from information held in a BIOS parameter  
block stored in the memory by the host file system.
3. All sectors within Subdirectories are system sectors.  
Subdirectory addresses and sizes can be identified by reading  
30 all Root Directory and Subdirectory entries.
- 20 4. System sectors are often read by a file system immediately  
before they are rewritten.

35 For the same purpose file data sectors to be relocated are  
written at the address defined by a Relocation Pointer (RP),  
25 and are therefore not intermingled with sectors written by the  
40 host.

In a modified embodiment of the invention, an additional write  
pointer may be provided to point to the location to which  
45 30 relocated system data is to be written. This additional  
pointer is referred to as the System Relocation Pointer (SRP),  
and is always located in a different block to the WP and SP.

#### 50 Block Erase Algorithm

5 No arbitrary selection of a block to be erased or scheduling  
of background erasure is carried out in the present invention.  
Listed erasure of a block containing obsolete sectors is  
10 normally immediately performed when an obsolete sector in a  
5 second block will result from a host sector write command  
which is pending. Similarly, a block is immediately erased  
when it contains totally obsolete control data structures as a  
15 result of the rewriting of a control block. (Control blocks  
are where the controller 8 writes certain control data, and  
20 are described in further detail later).

20 Therefore, normally, since relocations cannot produce obsolete  
data, there can exist not more than two blocks which contain  
obsolete data; the Current Obsolete Block (COB) corresponding  
25 15 to the Data Write Pointer (WP) and containing obsolete file  
data and the Current Obsolete System Block (COSB)  
corresponding to the System Write Pointer (SWP) and containing  
obsolete system data. However, temporarily there may exist  
30 one more obsolete block of each type. This will occur when a  
20 block to be erased (obsolete data has just been created in  
another block) at this moment also contains a write pointer of  
any type. In this case erasure of such a block (designated  
35 Pending Obsolete Block (POB)) has to be postponed until all  
erased pages in this block have been used and the relevant  
25 write pointer will be moved to another block. At this moment  
the Pending Obsolete Block is immediately erased.  
40

As aforementioned, erased block identity is maintained in a  
BitMap (MAP) spanning the whole FLASH block address space, in  
45 30 which MAP the erased state of each block is recorded. Erased  
blocks are consumed for sector or control data writing  
sequentially in block address order. No background erasure is  
carried out. Any block containing one or more bad sectors is  
50 treated as a Bad Block and is treated as a "not erased" block  
35 by the controller.

### Wear Levelling

The use of cyclic write pointers and single sector write management produces inherent wear levelling in the FLASH memory. However, the algorithm of erasing blocks as soon as they are populated with obsolete or deleted data produces a wear levelling characteristic which is a function of the sequences of sector write operations. If any further wear levelling is thought to be necessary, then separate additional techniques may be incorporated, such as occasional relocation of sectors in random blocks so as to allow these blocks to be erased.

### Address Translation Principles

The principal address translation means is the Sector Address Table (SAT), which basically is a list of physical addresses of sectors, ordered by logical address. Thus the Nth SAT entry normally contains the physical address for sector with logical address N. The SAT is organised as a number of independent blocks (SAT blocks), and is updated by rewriting individual pages of the SAT blocks. A SAT block may have a dedicated Additional SAT Block (ASB) linked with it to allow modification of individual pages of the SAT Block. SAT pages are not rewritten after each sector write, but on a much less frequent basis, to minimise impact on sector write performance.

Therefore, the SAT will not contain the correct physical address for sectors written since the SAT was last updated. The logical addresses of such sectors are stored by the processor in its SRAM 13 in lists called the Write Sector List (WSL), Relocation Sector List (RSL) and Write System Sector List (WSSL). These lists exactly match the ordering of the sectors themselves which were written by a host or relocated from blocks before erasure. In the case of consecutively

5 written sectors the WSL and RSL entry defines first sector  
logical address and the sector group length. The sector  
groups cannot jump from one block to another. The  
10 microprocessor 11 has knowledge of the starting point of the  
5 sector series in Flash memory, and also the order in which  
blocks were used for sector writing (special lists,  
complimentary to those described above and created in the  
15 processor SRAM, namely the Write Block List (WBL), Write  
System Block List (WSBL) and Relocation Block List (RBL), are  
10 used to store this information and are described in further  
detail later), and so can calculate the physical location of  
20 the sector.

The WSL, RSL and WSSL (and lists, complimentary to them: WBL,  
25 15 WSBL and RBL) can be recreated by the microprocessor 11 after  
removal and restoration of power to the memory system 10 by  
reading the logical addresses in the headers of the sectors in  
the series written since the last SAT rewrite. The starting  
30 sector address in the series and the links between blocks  
20 containing sectors in the series is obtained by the  
microprocessor from entries in a special data structure called  
the Control Block (CB) in Flash memory. (The Control Block  
35 (CB) is described in detail later). This method gives high  
security of data in the event of unexpected power removal from  
25 the card.

40 It will be appreciated that where a System Relocation Pointer  
(SRP) is included, as mentioned above, a System Relocation  
Sector List (SRTL) and complementary System Relocation Block  
45 30 List (SRBL) are also created and used in a similar manner as  
described above with regard to the WSL, RSL and WSSL, and the  
WBL, RBL and WSBL, respectively.

50 The organisation of data in a FLASH Sector (i.e. page) 1 to  
35 which data is written by the controller 8, according to the

5 present embodiment, is illustrated in Fig. 3. The Sector 1  
contains a first, 512 Byte information portion 1a which may,  
for example, consist of a host data sector, followed by a 4  
10 byte header portion 1b, followed in turn by 12 Bytes of ECC  
5 1c. As shown in Fig. 4, the Header portion itself comprises a  
Data Structure Type portion 20 and a Header Parameter 22 (e.g.  
comprising the logical sector address (LA) of a host data  
15 sector written in the information portion 1a. The Data  
Structure Type can have values representing any one of the  
10 following : Data Sector; Deleted Data Sector; Sector Address  
Table (SAT) page; Additional SAT Block (ASB) page; Control  
20 Block (CB) page; and Boot Block (BB) page.

#### Deleted Data Sector

25 A deleted data sector physically exists temporarily in the  
FLASH memory only in blocks which are permitted to contain  
obsolete or deleted sector data i.e. the COB or COSB. It is  
identified by the "all zero" state of the Data Structure Type  
30 field in the header, or other means as appropriate.

20

#### Sector Address Table (SAT)

35 The SAT is a series of entries containing the physical address  
of logical sectors. Entry N contains the physical address for  
logical sector N. Entries within a page occupy the 512 bytes  
25 of the information portion 1a of the data stored in the page.  
Because a SAT page is written in a single operation, the EEC  
40 field may be used to protect the complete page, and separate  
ECC fields for each entry in the SAT page are not required.

45 30 The SAT is actually stored as a series of blocks, each block  
containing up to 64 SAT pages. A separate data structure, the  
Table Block List (TBL), is held in the Control Block  
50 (described later) to define the block addresses of all SAT  
blocks. Each SAT entry defines the physical address of a  
35 sector and occupies 3 bytes and as shown in Fig.5 comprises:



5  
10  
15  
20  
25  
30  
35  
40  
45  
50  
55

Chip Number 5 bits, allows 32 chips to be addressed  
Block Number 13 bits, allows there to be 8192 blocks per chip  
Sector Number 6 bits, allows up to 64 sectors per block.

The Header Parameter field on a SAT page data structure contains the SAT block and page number.

A Flash card with capacity 8MB and 8VB blocks can store approximately 16K sectors, and its SAT will therefore have approximately 16K entries. A 512-byte page within a SAT will contain 170 entries, and the SAT will therefore occupy almost 96 pages, which will occupy 6 blocks. A SAT for a large FLASH memory card (2GB, 8VB blocks) occupies 1543 blocks.

#### Additional SAT Block (ASB)

An Additional SAT Block (ASB) is a dedicated block which may be linked to a specific SAT block to allow single pages of the SAT block to be modified (i.e. rewritten). There can be several ASBs, each of which acts as an extension to the SAT block to which it is linked. When a SAT block is to be modified, it generally contains modified data in only a small number of its pages. The ASB allows only these modified pages to be rewritten. This is a much faster operation than the writing of every page and erasure of the obsolete block which is required for rewriting a SAT block. The Header Parameter portion of an ASB page contains the SAT block to which it is linked and the SAT page number within that block which it replaces. The format of the information portion 1a of data stored in an ASB page is identical to that of a SAT page.

#### Control Blocks (CBs)

The Controller 8 stores some control and address information in one or more Control Blocks (CBs). The CBs are updated

periodically by the controller 8 and must be accessed during  
initialisation of the memory system 10 or occasionally during  
operation. Information is stored in the CBs in entries of a  
fixed size which can be independently written. There are 9  
5 entries per page in each CB. An entry relates to one of the  
following list of data types, which are identified by a CB  
Header field in the entry itself :

- Table Block List (TBL)
- Map of blocks with some fields in the entry corresponding to  
10 a file data write operation (WMAP)
- Map of blocks corresponding to a system data write operation  
20 (SMAP)
- Map of blocks corresponding to a relocate sector operation  
(RMAP)

15 When new data must be added to the CB, an additional entry of  
the appropriate type is added immediately following the last  
valid entry. For large cards the CB may occupy more than one  
block. The addresses of all CB blocks are stored in a Boot  
30 Block (BB) in the FLASH memory 6.

20

For purposes of data security the first page (designated  
Header Page) of each block of a CB (and the BB also) does not  
35 contain entries and has a full page format of like that of  
Fig. 3. The Header Parameter field of the Header 16 of this  
25 page consists of a Signature, which identifies the CB, and its  
Block Number (which is the block's serial number within the  
40 set of Control Blocks).

The Information Field 1a of the Header Page of the first CB  
45 30 block is occupied by a Block Link Info data. The Block Link  
Info data provides all necessary information to restore the  
WBL, WSBL and RBL if the system has to be initialised  
50 following a CB rewrite operation. It comprises Link fields  
collected from all MAPS (WMAPS, SMAPS and RMAPS) written since

5 the last SAT page write operation was performed and has to be  
written to the Header Page of the first block of a new CB  
during its rewrite operation. The Block Link Info is a timing  
10 ordered list of 4 bytes entries, each of which contains a  
5 block address of a block being visited by one of the write  
pointers and a flag identifying which pointer it was. A  
maximum number of blocks in memory space is allowed for CBs  
15 and when this becomes full, active entries are rewritten to  
the next available erased block(s) from the NEB (i.e. it is  
10 compacted and corresponding Header Pages are added), and the  
old CBs are erased. (At the same time a corresponding entry  
20 has to be added to the Boot Block.) The information field of  
a CB page contains 9 entries of equal length. The EEC field  
of a CB page is not used or may be used for other purposes.

25 15  
An entry in a CB is 56 Bytes wide and has the format shown in  
Fig.6 and comprises a Header 24 identifying the data type of  
the entry, an information field 26, and an EEC field 28. The  
30 EEC is of the same form as is used for a full page.

20

#### Table Block List (TBL)

35 The CBs contain the Table Block List (TBL). The TBL contains  
the addresses of a group of contiguous blocks of the SAT and  
any corresponding ASBs. Multiple TBLs are normally required  
25 to define all required SAT block addresses. The relevant TBL  
is written immediately after a SAT block write operation or  
40 allocation of a new ASB, to record the modified SAT or ASB  
block locations. The TBL also contains fields which are used  
to record write pointer positions at the moment when a SAT  
45 30 page write operation is to be performed. Therefore, a TBL is  
also written whenever a SAT page write operation is carried  
out. One entry of the TBL is shown in Fig. 7 and occupies the  
50 information field 26 of a CB entry. The first 1 Byte of the  
TBL entry is No, a sequential number of the TBL entry. Each  
35 TBL entry keeps values of 8 SAT - ASB block pairs, in other

5 words each TBL entry keeps values for SAT blocks from N to N+7  
where N is No\*8.

10 WP is the Write Pointer Page field, RP is the Relocation  
5 Pointer field, and SWP is the System Write Pointer field.  
These fields determine the position of the WP, RP and SWP  
within the blocks after WSL, RSL, SSL release operation. WP,  
15 RP and SWP are valid only when WSL, RSL or SSL release  
operation is complete (i.e. at the last SAT write operation).  
20 This condition is set with the Flag bit in the entry Header.  
Flag=1 means the entry is the last one written during WSL or  
RSL release and so WP field is valid.

3 reserved bytes are left for possible future additions.

25 SAT-ASB Pairs follow reserved fields, this is an array of 8  
entries, each consists of SAT and ASB block addresses.

30  $SAT_N$  is the number of the Nth SAT block and  $ASB_N$  is the number  
20 of the ASB linked to the  $SAT_N$ . If SAT or ASB doesn't exist  
the value of this field should be equal to zero.

35 New TBL entry should be added to CB each time SAT block is  
relocated or new ASB is linked to SAT block.

40 MAP (WMAP, SMAP and RMAP)

The CBs contain various MAP entries. There are three  
different types of MAP entry each of which corresponds to a  
different type of write operation; WMAP - to a file data write  
45 30 or delete operation, SMAP - to a system data write and RMAP -  
to a sector relocation operation.

50 The information field of all the MAP entries has the same  
format. It contains a BitMap defining the erase state of a  
35 group of consecutive blocks. The erase state of 256 blocks is

5 defined by the 256 bits in a 32 byte field in the MAP. The  
information field contains a Range field identifying the group  
of blocks to which it relates. Another field defines the  
10 destination block for a transition of the write pointer  
5 between blocks. The MAP also contains fields identifying the  
location of blocks in flash memory containing obsolete data;  
ObsC is used for the COB (or COSB) and ObsP - for the Pending  
15 Obsolete Block. If obsolete block is not present  
corresponding field is set to 0. The EB field contains an  
10 address of a block in which erasure is caused by current write  
or delete sector operation. If there is no such block the EB  
20 field is set to 0. This MAP entry format is illustrated in  
Fig.8.

25 15 When one of the write pointers is moved from one block to  
another, a corresponding MAP entry must be added to show the  
use of an erased block (the BitMap field is updated) and to  
record the link between the blocks (the Link field is  
30 updated). When a write (or delete sector) operation produces  
20 obsolete (or deleted) data in a new block, a corresponding MAP  
also must be added to record a new obsolete block position  
(ObsC or/and ObsP fields are updated), to indicate that a  
35 block has to be erased (the EB field is updated) and to show  
that a new erased block is going to appear (the BitMap field  
25 is updated). Therefore, normally, at least two fields of a  
MAP are written at the same time and this may be achieved in a  
40 single page write operation.

#### Boot Block (BB)

45 30 The function of the Boot Block is to provide high security of  
data in the event of unexpected power removal from the card  
and at the same time avoid extensive scanning during  
50 initialisation procedure. For large cards the BB contains  
more than one block. The BB always occupies the first  
35 nondefective block(s) in the card. For purpose of data

5 security there is a copy of the BB occupying the next  
nondefective block(s) in the card. Both the BB and its copy  
must be put to the same place after being rewritten.

10 5 The BB has the same structure as the Control Block and  
contains the following types of entries :

- Signature
- 15 • Interleaving Enable.
- Bad Block List

10 • Control Block Pointers Table (CBPT)

20 When new data must be added to the BB, an additional entry of  
the appropriate type is added immediately following the last  
valid entry. The Signature and the BBL entries have just the  
same format as described before (of course, the signature  
25 field in the signature entry is different and unique). The  
Control Block Pointers Table entry contains pointers to all  
blocks of the CB and has to be updated immediately after the  
CB is rewritten.

30 20 Previous Link (PL)

The CB(s) also contain the Previous Link (PL). The purpose of  
35 the Previous Link is to provide all necessary information to  
restore the WBL (described later) if the system has to be  
initialised following a CB rewrite operation. It comprises  
25 Link fields collected from all MAPs written since the last SAT  
page write operation has been performed. The PL has to be  
40 written only to a new CB during its rewrite operation.

Data Structures Stored in SRAM of Controller

45 30 Various data structures are stored in the SRAM 13 of  
microprocessor including the following :

50 Write Sector List (WSL) (or "whistle")

5 The Write Sector List records the logical addresses of sectors  
written after the last SAT write. Its purpose is to allow  
correct logical-to-physical address translation for such  
10 sectors. The WSL has capacity for 128 entries of length 4  
5 bytes, where each entry stores the logical address of the  
first sector in a group of consecutively written sectors and  
the group length. The sector groups cannot jump from one  
15 block to another. The WSL is empty immediately after a SAT  
write.

10

20 The ordering of logical sector addresses in the WSL exactly  
matches the order in which they were written. A non-volatile  
copy of the WSL in Flash memory is therefore automatically  
provided by the headers of the actual sectors written at  
25 consecutive locations starting at that defined by the Write  
Pointer (WP) at the time the SAT was last written. There is  
therefore no need to explicitly make copies of the WSL to  
Flash memory 6. If necessary, these sectors can be scanned  
30 from a starting address defined in a Control Block field which  
20 contains the position of the Write Pointer (WP) at the time  
the SAT was last written, along with the Link fields from  
subsequent MAP entries.

35

Search of the WSL is performed in reverse order, since only  
25 the last entry for any logical sector is valid. Duplicate  
earlier entries may not have any corresponding obsolete sector  
40 located in Flash memory because sector relocations and block  
erasures may have been performed. If preferred, the controller  
is configured to simply remove duplicate entries from the WSL.

45

30

Two similar lists, the Relocation Sector List (RSL) and System  
Sector List (SSL), are also compiled in the microprocessor  
50 SRAM 13 recording the logical addresses of relocated sectors  
and System data sectors (written to addresses pointed to by  
35 the RP and SWP respectively) written since the last SAT write.

55

5 An ASB and/or a SAT block is supplemented with WSL, RSL or SSL entries every time the WSL, RLS or SSL respectively is full. This procedure is called WSL, RSL or SSL release. This  
10 release can cause ASB release if necessary. ASB release occurs when an ASB is full. When an ASB is full the respective SAT block is rewritten and the ASB is erased.  
15 Information about written pages in all ASBs should be stored in RAM to avoid frequent ASB scanning. An ASB List (ASBL) for  
20 this purpose is stored in the SRAM 13.

20 The ASBL is a list of all the ASB blocks currently linked with SAT blocks, there being one entry in the ASBL for each ASB. Fig.9 illustrates the format of one entry in the ASBL, where :  
25 LWP = number of last written page in this ASB block  
NVP = number of the valid pages in ASB block minus one.  
ASB Page 0 ... ASB Page n = an array, index is ASB page number, value is corresponding SAT page number.  
30 N = pages per block.

20

#### Write Block List (WBL)

35 The Write Block List is complementary to the Write Sector List and is created in microprocessor SRAM 13 to define the blocks within which the sectors in the WSL are located. The WBL is  
25 empty immediately after WSL release.

40 The WSL and WBL are recreated by a scanning process during initialisation of the memory system. The lists in SRAM which are created in this way will exactly match the lists which  
45 30 existed before power was last removed.

Two similar lists to the WBL named the Relocation Block List (RBL) and System Block List (SBL), are also compiled and  
50 stored in the SRAM 13, these lists being complimentary to the  
35 RSL and SSL respectively. The RBL and SBL define the blocks

55



within which the sectors in the RSL and SSL respectively are physically located, and are of similar format to the WBL. The RSL, RBL, SSL and SBL can also be recreated by a scanning process during initialisation of the memory system.

5

#### Current Obsolete Block (COB)

Only one block is allowed to exist which contains obsolete or deleted sector data written by the Write Pointer (WP). This is named the Current Obsolete Block (COB). When obsolete or deleted sector data is created in another block, an erase operation must be performed immediately on the block defined as the COB. The current block address of the COB and also a list of sectors which became obsolete or were deleted in this block are stored in the microprocessor RAM 13 as a data structure hereinafter referred to as the COB Structure. The COB Structure is established during initialisation by copying a field containing obsolete block address from the latest MAP entry, and then adding obsolete sector addresses after the reconstructed WSL and WBL have been analysed and reading deleted sector addresses from this block. The COB Structure is updated every time a new delete sector operation is performed or a new obsolete sector is created, and the block address is copied to a current MAP entry in the CB every time obsolete data is created in a new block.

25

There is also allowed to exist one block which contains obsolete or deleted sector data written by the SWP, named the Current Obsolete System Block (COSB). The COSB Structure is also stored in the SRAM 13 in a similar manner to the COB Structure. The COB and COSB each have the format shown in Fig. 10, namely a 4 byte Block Number field 28 (this is the block address of the COB or COSB) and a 32 byte Obsolete or Deleted Sector Mask 30 which is a BitMap containing ones in positions corresponding to obsolete or deleted sectors inside

5 this block. For a block comprising 256 pages this mask 30  
takes 32 bytes.

Next Erased Block list (NEB)

10 5 The Next Erased Block list is created in the microprocessor  
SRAM 13 in order to provide fast identification of the next  
available erased block when incrementing the WP, SWP and RP  
15 between blocks. Available erased blocks are used in ascending  
order of their physical addresses. The NEB contains M erased  
20 block addresses, (e.g. M=8). The NEB list is a list of next  
available erased blocks, starting with the erased block with  
block address closest to and higher than the address of the  
last erased block to be allocated for use. Thus, although the  
number of entries in the NEB is limited (e.g. to 8), the NEB  
25 15 itself may contain information about more than the next eight  
erased blocks.

The Next Erased Block list is derived from the MAP entry  
30 (stored in CB) appropriate to the region of Flash memory  
address space being accessed by the write pointers. This will  
remain in SRAM as the active NEB until all erased blocks  
defined by it are used, at which point it must be recreated  
35 from the appropriate MAP entries. The CB contains sufficient  
MAP entries to define the erase state of every block in Flash  
25 memory. Both the NEB and the corresponding MAP entry are  
updated by addition and removal of blocks during operation of  
40 the memory system. An entry is removed from the NEB when an  
erased block is allocated for sector or control data storage.  
An entry is added to the NEB (unless the NEB is already full)  
45 30 when an erased block is created at a block address which lies  
within the range spanned by the other blocks in the NEB.

50 A single NEB entry defines a group erased blocks at contiguous  
addresses, and defines the block start address (the first

block address in the contiguous group of blocks) and the group length (number of contiguous blocks in the group).

#### TBL Pointers (TBLP)

The TBL Pointers identify positions of TBL entries in the CB. They are also stored in the microprocessor SRAM and are used to provide fast sector address translation. The TBLP is created during initial scanning of the Control Block, and then is updated every time a new TBL entry is created in the CB.

#### ASB List (ASBL)

As aforementioned, the ASBL is created in SRAM 13 and supports fast address translation. It identifies the physical addresses of all ASB blocks and the SAT blocks with which they are associated. It is created during initialisation and has to be updated each time a SAT page write operation is performed. The ASBL entries are listed in order of previous accesses, that is, when an entry is accessed it is promoted to the top of the list. When a SAT block which does not currently have an associated ASB is accessed, an ASB is allocated and an entry for it is added at the top of the ASBL. The bottom entry of the ASBL, representing the least recently accessed ASB, is eliminated.

#### SAT Cache

A cache is maintained in the SRAM 13 for 32 contiguous SAT entries incorporating the entry most recently accessed from a SAT in Flash memory.

#### Capacity Map

Total Flash memory capacity in the memory system 10 is allocated to data and control structures as follows :

##### 1. Logical Sectors

Capacity is allocated to storage of one valid data sector for each logical address within the declared logical

capacity of the card. This declared capacity is the available physical capacity minus items 2 to 8 below, and is defined by the formatter during card manufacture.

2. Boot Block

At least one block is allocated to the boot block. Preferably, a second block is allocated for storing another copy of the boot block.

3. Control Block

A number of blocks are allocated to storage of Control Block entries (Signature, BBL, TBL and MAP). The fully compacted Control Block occupies less than one block in most cases. Additional blocks are allocated to the Control Block for entries written between compaction/rewrite operations.

4. Sector Address Table

This is the capacity allocated to the storage of the blocks of the SAT. It is proportional to the logical capacity of the card.

5. Additional SAT Blocks

A fixed number of blocks are allocated for ASBs to be associated with defined SAT blocks.

6. Obsolete Sectors

One block is allocated for the COB. Another block is allocated for the COSB and one further block is allocated for the POB (for embodiments which allow the existence of a COSB and POB). The maximum number of permitted obsolete data sectors is therefore set by the number of pages in a block.

7. Erased Buffer

This is a buffer of erased blocks which must be allocated for correct operation of the system. At least one erased block must be allocated for data sector relocation and one for control structure relocation which may take place concurrently.

8. Spare Blocks

Spare blocks may be allocated for use to maintain declared logical capacity in the event of a failure during operating life. The number of spare blocks is determined by the formatter during card manufacture.

5

A Capacity Allocation Table illustrating, for example purposes, capacity allocated to the above items 1-8, for an 8MB card, 64MB Card and 512MB Card (FLASH Cards) is shown in Fig. 16 (this shows only one block allocated for obsolete sectors, namely for the COB, but it will be appreciated that more blocks will be allocated for obsolete sectors where there is provision for a COSB and/or POB in the memory system).

#### SAT WRITE OPERATIONS

The SAT is rewritten when the WSL, WBL, SSL, SBL, RSL or RBL, is full and, in the majority of cases, it is done with a granularity of one page, that is, only SAT pages containing modified sector addresses are rewritten. However, in a small minority of cases, full SAT block rewriting is required (designated "SAT block write"). When a SAT rewrite is required, an Additional SAT Block (ASB) is created, into which only the required pages are written (designated "SAT page write"). There can only be one ASB dedicated to a specific SAT block, and totally, there may exist a limited number N of ASBs. The value of N will be chosen as an appropriate compromise between write performance and capacity overhead (for example, N=8).

Each ASB exists until a "SAT block write" is performed on its associated SAT block. A SAT block write is performed when a SAT write page is required on a SAT block whose ASB is full or an ASB is to be deallocated. When a SAT page write is required and the corresponding SAT block does not have an associated ASB and all N ASBs are already allocated, one of the existing ASBs has to be deallocated before allocation of a

5 new ASB. The ASB to be deallocated is selected as the one  
which has not been written for the longest time. Note that  
deallocation of an ASB is rather time consuming procedure as  
10 it requires writing of a SAT block and also erasure of both  
5 the obsolete SAT block and ASB.

#### Interleaved Chip Access

15 The above described operations and data structures inherently  
allow interleaved write operations to be performed on several  
10 Flash chips 5 and this can significantly increase performance.  
The controller chip 8 may thus control a plurality of FLASH  
20 chips 5, for example an array of four FLASH chips,  
incorporated in the memory system. The memory space of the  
four FLASH chips is organised by the controller as a set of  
25 virtual blocks, each of which consists of four blocks 4, one  
block from each of the four chips 5 (which chips are  
permanently linked together). The four blocks in each virtual  
block are the blocks with the same block address within a  
30 chip. This organisation allows linked blocks forming a virtual  
20 block to be treated as one large block and, therefore, to use  
all the same described algorithms and data structures as  
previously described for a single FLASH memory system 10,  
35 using virtual blocks instead of the individual erasable blocks  
of sectors. Page write operations are performed concurrently  
25 across all interleaved chips. The Write Pointer (WP) and the  
RP and SWP each move sequentially through page addresses, and  
40 the ordering of address bits supplied to a hardware chip  
enable decoder provided in the controller 8 ensures that pages  
of linked blocks are sequentially accessed in the order  
45 illustrated in Fig. 11 i.e. each pointer WP, SWP, RP moves  
from one chip to another when moving from one PA to another  
PA. This is achieved by the use of Virtual Addresses. A  
unique Virtual Address (VA) is allocated to each physical  
50 sector (e.g. in the above-described NAND based memory system a  
35 VA is allocated for each page) in all of the chips. The

5 Virtual Addresses are allocated such that incrementing the VA  
by one moves the write pointer from one chip to the next chip,  
the Virtual addresses incrementing from chip to chip, though  
10 linked blocks of each virtual block, in a repeating pattern as  
5 shown in Fig. 11.

15 The controller in effect treats the array of memory chips as a  
single column of virtual blocks. The Virtual Address of a  
sector takes the format shown in Fig. 12. This consists of a  
10 Virtual Block portion comprising a ChipHigh portion and the 13  
bit Block address of the sector, and a Virtual Page portion  
20 comprising the 6 bit page address and a ChipLow portion. The  
ChipHigh portion is  $C_{high}$  bits of the 5 bit chip number (of the  
physical address - see Fig. 5) and the ChipLow portion is  $C_{low}$   
25 15 bits of the 5 bit chip number, where:

$C_{high}$  = column number of chip in array of chips; and

$C_{low}$  = row number of chip in array of chips.

30 To obtain the Physical Address (PA) from the Virtual Address  
(VA), the controller simply re-organises the VA so as to move  
20 the ChipLow portion back between the ChipHigh and Block  
address portion, as shown in Fig. 13. Thus, it will be  
appreciated that in a single chip memory system for any sector  
35 the VA is equal to the PA.

25 For simplicity, only a number of chips which is a binary  
multiple may be interleaved, for example, 2 or 4. Erase  
40 operations on virtual blocks are performed as concurrent  
erasures of all linked blocks of interleaved chips. If a block  
in a chip is a bad block the controller treats all the blocks  
45 30 having the equivalent block address in the other chips as bad  
blocks.

50 Interleaving is enabled or disabled according to the status of  
a control byte in the Boot Block which is set in enabled or

disabled status by the manufacturer of the memory system when the FLASH memory is formatted.

Where block addresses or PAs were previously used in the above-described single chip NAND type FLASH embodiments, we now use Virtual Block addresses and VAs, respectively. On receipt of a host data sector write command the controller translates an incoming LA to a PA by allocating the PA to which the relevant write pointer is pointing. The controller controls the write pointers to each move through the PAs so as to, in effect, move sequentially through the Virtual Addresses (VAs) of the sectors of those of the virtual blocks which are erased (which erased virtual blocks are identified in the NEB).

Fig. 14 illustrates the timing of the various operations involved in a multiple sector write to interleaved chips. Fig. 14 will now be described with reference to Fig. 15 and Fig. 19. Fig 15 is a block diagram illustrating in detail the controller chip 8 of the memory system. (The controller chip 8 of Fig. 2 may be of the form shown in Fig. 15 and like parts in both Fig. 2 and Fig. 15 are numbered with the same reference numerals). Fig. 19 is a schematic diagram of a memory system 10 comprising the controller chip 81 and four FLASH chips 1<sup>1</sup>, 2<sup>1</sup>, 3<sup>1</sup>, 4<sup>1</sup> each with its own read/write buffer 71<sup>1</sup>, 72<sup>1</sup>, 73<sup>1</sup>, 74<sup>1</sup>.

Fig. 15 shows the controller chip 8<sup>1</sup>, with : an input/output port O/P e.g. a PC Card ATA Port, Compact Flash or IDE Port, for connection to a host computer; a Host Interface & Registers 80 connected to O/P and a Dual-Port SRAM Sector Buffer 9 connected thereto; A Datapath controller 82, the ECC Generator & Checker 12, and a Flash Memory Interface (FMI) 84, all connected to the Sector Buffer 9, the FMI also being connected to a Flash Memory Port 86. The controller 8 also



5 includes microprocessor 11 (in the form of a RISC Processor);  
processor SRAM 13.; a processor Mask ROM 88; and a port for an  
external Program RAM or ROM 92. An optional Debug Port 94  
10 may also be provided for the RISC processor 11. Data and  
5 commands are communicated between the various components of  
the controller 8<sup>1</sup> (except for the Sector Buffer 9) via a  
microprocessor Bus 91.

15 As shown in Fig. 14, when a multiple sector write command (in  
10 this case a 4-sector write comprising Host Data sectors 1, 2,  
3 & 4) is received at the ATA Port O/P, Sector 1 is written  
20 into a Buffer 1 of the Dual-Port Sector Buffer 9. This leaves  
a Buffer 2 of the Sector Buffer 9 available for controller  
data management operations. When Sector 2 is received it is  
25 written directly into Buffer 2 and at the same time Sector 1  
is moved from Buffer 1 to the Flash Memory Port 86 from where  
it is written into the read/write buffer 71<sup>1</sup> of one of the  
four FLASH chips (chip 1<sup>1</sup>). Sector 2 is then sent from buffer  
30 2 to the Flash port 86 and on to the read/write buffer 72<sup>1</sup> of  
20 one of the other four FLASH chips (chip 2<sup>1</sup>). While this is  
happening Sector 3 is received directly into Buffer 1 of the  
Sector Buffer 9. Sector 3 is written to the buffer 73<sup>1</sup> of  
35 Chip 3 and Sector 4 is received into Buffer 2 of the Sector  
Buffer 9, and is then written to the buffer 74<sup>1</sup> of chip 4.  
25 Sectors 1,2,3 and 4 are then written into the relevant  
allocated physical sectors in the memory arrays 61<sup>1</sup>,62<sup>1</sup>,63<sup>1</sup>,64<sup>1</sup>  
40 of chips 1<sup>1</sup>, 2<sup>1</sup>, 3<sup>1</sup> & 4<sup>1</sup> respectively. Although Fig. 14 shows  
each such sector Write operation starting shortly after the  
previous one, in practice, to all intents and purposes, it  
45 30 will be appreciated that the four Sectors 1,2,3,4 are written  
substantially concurrently to the Flash Chips 1<sup>1</sup> to 4<sup>1</sup>.  
Moreover it will be appreciated that the physical addresses of  
the sectors to which the Host Data Sectors 1 to 4 are written  
50 are determined by the algorithms previously described which

determine the position of the relevant write pointer (i.e. sequential use of Virtual Addresses).

It will be appreciated that where a multiple-sector write command of more than four sector writes is sent from the host processor to the controller, the controller partitions the multiple-sector write into groups of (for the present embodiment using four memory chips) four sectors, each such group to be written to FLASH memory in an interleaved write sequence as described above with reference to Fig.14.

#### Address Translation

The process of address translation for an LA to a VA will now be described in further detail, with reference to read and write operations.

Address translation is an operation performed on the logical address of a sector which returns one of the following three values:

- Valid sector physical address
- Information that logical sector has been deleted (or has never been written)
- Information that an error condition has occurred

Fig. 17 is a flow chart illustrating the address translation process. This process is carried out for every read operation. When a logical sector address (LA) to be translated is received by the controller 8<sup>1</sup> from the host processor an algorithm is implemented (box 40) to identify the possibility that a sector whose logical address is to be translated has previously been written or deleted since its SAT entry was last written. A conclusion that a sector has not been previously written or deleted must be 100% certain; a conclusion that a sector may have been previously written or deleted should have a high probability of being correct. This

5 is carried out by the processor by keeping a limited number of  
pairs of values representing the start and end addresses of  
contiguous sequences of sectors, and identifying whether an  
10 address to be translated lies within any of these ranges.  
5 These ranges may eventually become non-contiguous, leading to  
some uncertainty in a conclusion that a sector may have been  
previously written or deleted. If the LA lies within any of  
15 the ranges then we answer "IS Repeat Possible?" (box 42 of  
Fig.17) with YES. If the LA does not lie within the ranges we  
10 answer NO and go to the SAT or SAT Cache to find VA (box 44).  
From here we determine whether the physical sector is Bad (46)  
20 or Deleted (50). If the LA corresponds to an unwritten sector  
this results in VA=Deleted (58) at box 50. If we answer Yes  
at box 42, then we search 52 the WSL or SSL (depending on  
25 whether the LA corresponds to file or system data). If at box  
54 the LA is found (YES) the VA is calculated 56 and the  
logical address stored in the header 1b is of the physical  
sector is read by the controller microprocessor (at 58). If  
30 LA=LA1 (box 60) then the calculated VA is correct. If the LA  
20 is not found at 54 then we search 62 for it in the RSL and if  
it is not found in the RSL we go to the SAT or SAT Cache and  
get the VA from there 44. If the VA found in the SAT or Sat  
35 Cache is not Bad or Deleted 46, 50, then we get LA1 from the  
VA 58 and check if LA=LA1, as before.  
25  
40 The process steps carried out at box 56 (Calculate VA) of  
Fig.17 are illustrated in detail in the flow diagram of Fig.  
20. Fig.20 illustrates the steps carried out in order to  
obtain the VA for an LA found in the WSL or RSL, for a memory  
45 30 system using only two write pointers, WP and RP. It will be  
appreciated that this flow diagram would be extended to also  
allow the VA for an LA found in the SSL, where the memory  
system also incorporates a System Write Pointer (SWP). The  
50 process starts at box 100 where we set NumFromEnd (NFE), where  
35 NumFromEnd = number of sectors written beginning from the end

5 of the WSL (or RSL) up to the given sector (found in the WSL  
or RSL. If the LA was found in the WSL we set  $P=WP$  and if LA  
was found in the RSL we set  $P=RP$ ; then we set  $PG= P.Page$  where  
10  $P.Page$  is the page of the write pointer indicated by the value  
5 of  $P$  (see box 102). If  $104 PG > NFE$  (i.e. LA is in the last  
written block) then  $VA= P-NFE-1$ , namely  $NFE-1$  sectors away  
from the position of the relevant write pointer. If  $PG < NFE$   
15 then we determine 106 if  $P==0$ , namely if a block corresponding  
the last WBL/RBL entry is fully written. If it is (i.e.  $P==0$ )  
10 we set  $NotLast=0$ , and if it is not we set  $NotLast=1$ . We then  
calculate 108 number of blocks,  $Nblock$ , between the last one  
20 and the block where the given sector lies, using the following  
algorithm:

$Nsect$  is a number of sectors between last written block page 0  
25 15 and the given sector;  
 $Nsect= NumFromEnd - PG$ ;  
 $Nblock= Nsect/BlockSize + NotLast$

30 We then calculate 110 page number in a block,  $PageNum$ , where  
20  $PageNum= BlockSize - Nsect \% BlockSize$ . If LA is in the WSL we  
then 112 get Block Address ( $BlAddr$ ) from the WBL, or if LA is  
in the RSL we get 114 Block Address ( $BlAddr$ ) from the RBL,  
35 where Block Address is a Virtual address of a block containing  
the given sector, using the following:

25 If LA is I WSL, then  $BlAddr= RBL[LBL - Nblock]$ , where  $LBL$  is  
40 an index of the last entry in the WBL;  
If LA is in RSL, then  $BlAddr= RBL[LRBL + Nblock]$ , where  $LRBL$   
is an index of the last entry in the RBL.

45 30 Then we calculate 116 the VA using:  $VA= Page0 + PageNum$ , where  
 $Page0=$  Virtual address of page 0 in the block containing the  
given sector.

50 Fig.21 is a flow diagram of the process used to Get VA from  
35 SAT or SAT Cache (box 44 in Fig.17). Fig.21 is generally self-

5 explanatory but further comments regarding specifically  
labeled boxes is given as follows:

10 Box 120 (Is LA in SAT Cache): LA is in the SAT Cache if  $LA \geq$   
5 FirstCacheEntry.LA < FirstCacheEntry.LA + CacheSize,  
where FirstCacheEntry.LA = the LA corresponding to the first  
SAT Entry in the Cache, and (global) CacheSize = number of  
15 entries in the SAT Cache;

10 Box 122 (Calculate Block and Page in SAT): We calculate SBNu  
which is a SAT block number for the given LA, and Spage which  
20 is a SAT page number for the given LA;

Box 124 (Calculate number of TBL entry): TBLNum is a number of  
25 15 the required TBL Entry, where  $TBLNum = SBNu/8$ ; and

Box 126 (Store part of SAT page in cache): If it is possible,  
32 entries starting with the last entry accessed are cached.  
30 If there are not enough entries then a group of 32 entries  
20 ending with the last entry in a page and including the last  
sector accesses is cached.

35 Fig.18 is a flow diagram illustrating the process steps for  
Box 58 (Get LA1 from VA) of Fig.17. It should be noted that  
25 the Header Parameter (HP) stored in the Page Header will be  
40 the value of the logical address (LA) incremented by one. This  
is because deleted sectors are marked by setting all bits in  
their headers to zero. This LA=0 cannot be stored in a header.  
We therefore set  $LA1 = HP - 1$ .

45 30

#### Read Operations

Fig.22 is a flow diagram illustrating the sequence of steps  
carried out to read a host data sector from a physical sector.  
50 The controller starts by translating the LA (received from  
35 the host) to a VA (box 130). This is done by carrying out the

process illustrated in the Fig.17 flow chart, already described. Once the LA has been translated to a VA, the content of the physical sector with address VA is read into the buffer 9 of the controller. The controller then checks (box 132) if the sector (i.e. the content of the sector) is deleted or bad. If it is deleted or bad, the controller sets all bytes of the host processor's data buffer to 0xFF (box 134). If the sector is not a deleted sector (box 136), the controller returns error status to the host (box 138). If the sector is a deleted sector, the controller returns valid status to the host (box 137). If at box 132 the controller determines that the sector is not deleted or bad, the controller goes straight to box 137 i.e. returns valid status to the host.

15

#### Write Operations

Fig.23 is a flow diagram illustrating the sequence of steps carried out to write a host data sector to a physical sector.. Fig.23 deals only with write operations for host file data, and thus written by the Write Pointer (WP), but it will be appreciated that the operations of Fig.23 would be appropriately extended to deal with separate system data writes where the memory system uses a separate write pointer for system data (i.e. the SWP). The controller starts by translating the LA (received from the host) to a VA (box 150). This is done by carrying out the process illustrated in the Fig.17 flow chart, already described. If the sector is Bad, the controller returns error status 154 to the host. If the sector is not Bad, then check if the sector is deleted and if it is deleted then check if WP is valid or invalid. WP is invalid (WP==0) when a full block has just been written and WP has to be moved to an erased block. If WP is not valid, we set the WP to a new (valid) physical sector address. When WP is valid, we add the LA to the WSL and perform any WSL or RSL release, and/or CB and CBPT compaction, which is

5 necessary. We then update 164 the ranges from the Evaluate  
Repeat Possibility algorithm (box 40 of Fig.17) and write the  
sector 166 from the controller buffer to the address of the  
10 WP, and return a valid status value 168 to the host. If, at  
5 box 156, we find the sector is not deleted we then check 157  
if the VA is in the COB. (The VA is in the COB if VA coincides  
with VB, where VB is a Virtual Block Number field (this is the  
15 Virtual Block address - see Fig.12) in the COB structure  
stored in SRAM 13. If the VA is in the COB, we record VA as  
10 obsolete 159 in the COB structure stored in the controller  
SRAM 13 (this is done by setting a corresponding bit to 1 in  
20 the BitMask field of the COB Structure in SRAM 13.) and then  
go on to box 158 (is WP valid). If the VA is not in the COB we  
change the COB 161 and then move on to box 159 (Mark VA as  
15 Obsolete).

25 Fig.24 is a flow diagram of the steps implemented at box 161  
of Fig.23 (Change the COB). Fig.24 is generally self-  
30 explanatory but should be read in conjunction with the  
20 following notes:

35 Box 200 (VA.B1, VB): VA.B1 is a Virtual Block field of VA, and  
VB is as above-described;

Box 202 (Is COB invalid): COB is invalid if VB=0. If VB is  
25 equal to zero this indicates that there are no obsolete data  
at this moment;

40 Boxes 203,204 (Calculate MaxRel): MaxRel is a maximum number  
of sectors to be relocated from COB. MaxRel=P.Page-1, where  
P.Page is a Page field (address) of the WP or RP;

45 30 Boxes 205,206 (Add Dummy Entries to WSL): If a block to be  
relocated is not fully written yet, corresponding "dummy"  
sector LAs must be added to the last WSL (RSL) Entry;

50 Box 207 (Relocate Sectors): See Fig.25;

5       Box 208 (Write WMAP): Write WMAP to the CB where EB+VB and  
corresponding bit in the BitMap is set to 1. Perform CB  
rewrite if necessary;

10       Box 209 (Update Lists): Find WRBArray entry equal to VB and  
5 mark it and any other entries for the same VB in WRBArray as  
invalid. The WRBArray is in fact the WBL and WSL lists which  
are actually stored in the same area of memory with the WBL  
15 entries at the start counting up and the RBL entries at the  
end counting down. The WRBArray is full when the two lists  
20 meet in the middle.

20       Box 210 (Setup COB): Update COB Structure in SRAM, VB field is  
set to VA.Bl, Obs and Del Mask bit corresponding to VA.Page is  
set to 1, all other bits are set to 0.

25       15 Fig.25 illustrates the steps implemented at box 207 (Relocate  
Sectors) of Fig.24. This should be read in conjunction with  
the following notes:

30       Boxes 220, 222 and 230: Perform a loop going through Obs and  
Del Mask field of the COB Structure in SRAM;

20       Box 223 (Is Sector Valid?): Sector is valid if ODMask[i]=0;  
zero value in COB Obs and Del Mask indicates that this page  
contains a valid sector;

35       Boxes 224 and 225: RP=0 if a block pointed to by the RP is  
already fully written;

25       Box 226 (Store LA from Page Header): LA got from Page Header  
is temporarily stored to be used in Add Entry to RSL;

40       Box 225 (RP=0): Add Entry to the RSL. Perform WSL/RSL release,  
if necessary.

45       30 Fig.26 illustrates the steps implemented in order to set the  
Write Pointer (WP), at box 160 in Fig.23. A similar process is  
used to set the RP at box 227 in Fig.25. Fig.26 should be read  
in conjunction with the following comments:



Box 240 (Is WRArray not full): WRArray is not full if  
Last<LastRE-1, where Last (global) is an index of the last WSL  
entry, and LastRE is an index of the last RSL Entry;

Box 242 (Is WRBArray not full): WRBArray is not full if  
5 LBL<LRBL-1, where LBL and LRBL are as previously defined with  
regard to Fig.20;

Box 244 (Lists Release): Perform SAT Page Write operation, SAT  
Block Write and CB rewrite if necessary;

Box 246 (Fill NEB): Select next N (N=NEBSize) erased blocks  
10 from MAPs stored in the CB;

Box 248 (Write WMAP): Write WMAP with Link field set to  
ErBlock and corresponding bit in BitMap field set to 0.  
Perform CB rewrite if necessary.

15 Fig.27 is a flow diagram of the process steps carried out in a  
delete sector operation. This is in the initial steps similar  
to a write operation (see Fig.23): the LA is translated 250 to  
a VA. If 252 the sector is deleted we return error status to  
the host 254. If the sector is not deleted we check 256 if the  
30 VA is in the COB and if it is not 261 in the COB we Change the  
COB 261 (same as Fig.24). If VA is in the COB we Mark VA in  
the COB as deleted 269, then we fill one of the buffers of the  
Dual port SRAM 9 (in the controller) with zeros 271, and then  
35 write this "all zeros" page from the buffer to the sector to  
be deleted (thereby deleting the sector). We then return valid  
status 275 (confirming sector has been deleted) to the host.

#### Initialisation

Initialisation procedures and power-loss recovery procedures  
45 will now be described. For simplicity, these are described  
with reference to a single write pointer system (i.e. only WP)  
but it will be appreciated that the procedures will be readily  
extended as appropriate for the multiple write pointer system  
50 (WP, SWP, RP).

5 All data and control structures are specially constructed to  
avoid generalised scanning during initialisation. Almost all  
control structures (except WSL and WBL) normally are derived  
10 from corresponding information stored in the CB. During  
5 initialisation of the card, it is necessary to perform  
following operations.

1. To read the last Control Block Pointers Table entry from the  
15 Boot Block and so identify the CB block(s) locations.
2. To reconstruct the TBLP by scanning the CB.
- 10 3. To scan header/ECC fields of pages sequentially following  
the write pointer position defined in the last TBL entry in  
20 the Control Block to identify sectors written since the last  
SAT rewrite and to construct the WSL and WBL.
4. To construct the NEB from corresponding MAP entries in the  
25 CB.
5. To construct the COB and ASBL.
6. To check if a block referenced in the ErB field of the last  
MAP is really erased. If not, to complete erase operation.

#### 30 Construction of WSL and WBL

During initialisation of the card, the last value of the Write  
Pointer (WP) to be stored is read from the latest TBL entry in  
35 the CB and a scan of page headers at successive pages from  
that location is performed to rebuild the WSL and WBL in  
25 processor SRAM. When an erased location is encountered, the  
end of the sequence of sectors written since the last SAT  
40 rewrite has been reached.

This sector scan must take account of the fact that the Write  
45 30 Pointer (WP) may jump from the end of a block to the beginning  
of a non-adjacent block. All block transitions made by the  
(WP) are recorded in the Link fields of MAP entries in the CB.

#### 50 Construction of COB and ASBL

5        These structures can be reconstructed by copying corresponding  
      entries from the CB. In addition, to construct the COB  
      structure (to identify deleted sectors in it) it is necessary  
10        to scan a current block containing these sectors, whose  
      address is defined in the Obs field of the last MAP entry in  
      the CB. To identify obsolete sectors in this block, it is  
      also necessary to scan WSL and WBL. In order to record ASBL  
15        pages we have to identify ASB addresses from the TBL and then  
      to scan their header/ECC fields.

10

#### Power-Loss Recovery

20        It is a requirement for the memory system that it should be  
      able to operate normally, and that no stored data should be  
      lost, when power is restored, whatever the circumstances under  
25        which power has been removed. However, it is not necessary to  
      restore the full normal state of the memory system immediately  
      after power-on, only to allow it to operate normally... A  
      normal state can be restored later as an exception, whenever  
30        any abnormal state is detected.

20

      The normal state of the Memory System may be degraded if the  
      supply voltage is removed whilst any of the following  
35        operations is being performed.

1. Writing of a data sector from a host
- 25 2. Writing of a data sector which is being relocated
3. Writing of an entry to a control data block (CB or BB)
- 40 4. Writing of a page to a control data block (SAT or CB)
5. Erasure of any block with obsolete sector or control data

#### 30 Power loss during writing of a data sector from a host

      In this case, the data being written may be lost, but the host  
      had not been informed that the write command had completed and  
      may write the sector again. An incompletely written sector  
50        may exist in Flash memory as a result of the partial write  
      operation. This is detected during initialisation when the  
35

5 value of the Write Pointer is established by reading the page  
headers in the block defined by the last Link parameter in the  
CB. The last detected sector should read fully to check its  
10 ECC, and the next page should be read to check that it is  
5 completely erased. If a partially written sector is detected,  
all other sectors should be relocated to a new Write Pointer  
position at the beginning of the next erased block, then the  
15 block should be erased.

10 Power loss during writing of a data sector which is being  
relocated

20 This is detected during the process of establishing the Write  
Pointer during initialisation, as above. The same action of  
relocating sectors and erasing the block should be taken. In  
25 addition, an incomplete relocation operation should be  
detected by comparing logical sector addresses immediately  
preceding the Write Pointer with those of obsolete sectors in  
the block defined by the Obs parameter in the CB. Any pending  
30 sector relocations should be completed during initialisation.

20

Power loss during writing of an entry to a control data block  
(CB or BB)

35 This condition may be detected during normal initialisation  
when entries in the CB and BB are read and their ECCs are  
25 checked. The entry should be ignored if its ECC shows an  
error. The earlier operation which initiated the CB or BB  
40 entry write operation had not completed correctly and the  
entry will later be written correctly when this operation is  
repeated during normal operation.

45 30

Power loss during writing of a page to a control data block  
(ASB)

50 This condition may be detected during normal initialisation  
when pages in the ASB are read and their ECCs are checked.  
35 The page should be ignored if its ECC shows an error. The

earlier operation which initiated the ASB page write operation has not completed correctly and the page will later be written correctly when this operation is repeated during normal operation.

5

Power loss during writing of a full control data block (SAT or CB)

This will result in an incomplete control data block existing in Flash memory, with no references to it by other data structures. This condition need not be detected during initialisation, and the block may be allowed to exist as a "lost block". The earlier operation which initiated the block write operation had not completed correctly and the block will later be written correctly when this operation is repeated during normal operation. At a later stage of normal operation, the lost block will be detected by a discrepancy with its MAP state, or by the discovery of a discrepancy in the number of erased blocks in the system (see Capacity Map in Fig. 16). Exception routines may then identify and erase the block, by full FLASH memory scanning if necessary.

Power loss during erasure of a block with obsolete sector or control data

This will result in an incompletely erased block existing in Flash memory. This condition is detected during initialisation when the state of the block referenced by the ErB field in the last MAP entry in the CB is checked. Re-erasure of this block can be performed, if necessary.

Further Alternative Embodiments

Various modifications to the above-described embodiments are possible without departing from the scope of the invention. For example, one alternative way of handling erasure operations is to always allow two COBs (and two COSBs) to exist: the advantage of this would be to make the best use of

5 memory capacity. In the above-described embodiment, we only  
allow one COB, but also allow a POB to exist temporarily when  
there is a write pointer in a block which we wish to make the  
COB. This means that there must at all times be enough erased  
10 memory capacity to allocate for a POB, should it be necessary  
to have a POB. It therefore is attractive to make the best use  
of this memory capacity and one way of ensuring this is to  
always allow two COBs to exist, therefore eliminating the need  
15 for a POB (the second COB can act as a POB, when required). In  
such a two COB system, when it becomes necessary to create a  
new COB we erase the older one of the two COBs (unless it has  
a write pointer in it in which case we erase the younger one).

With reference to Fig.3, and the description of the  
25 arrangement of data in each of the FLASH pages in the memory  
system, we also propose some alternative ways of storing the  
data within a page. Fig.28 shows the physical partitioning of  
a typical 528 Byte NAND or AND type FLASH memory page 1. The  
30 page comprises a 512 Byte "data area" 300 and a 16-Byte "Spare  
area" 302. In the embodiment described above with reference to  
Fig.3, the controller 8 stores 512Bytes of information 1a  
(e.g. one host data sector) in the Data Area 300, and stores  
35 the Header 1b and ECC 1c (together referred to hereinafter as  
Overhead Data (OD)) in the Spare Area 302. However, other  
arrangements of data within the page 1 are possible. For  
example, as shown in Fig.29, the Header 1b and ECC 1c could  
40 equally be stored in a first portion 303 of the Data Area 300,  
and the Information 1a stored in the portion 304 consisting of  
the Spare Area 302 and the remainder of the Data Area 300.

45 30 Another possibility, shown in Fig.30, is to write the Header  
1b and ECC 1c at a position offset from the start of the FLASH  
page, and to write the Host Data Sector (which may be referred  
50 to as the "user data") in the remaining space either side of  
the Header and ECC. By how much (Offset S) the OD is offset

5 may, for example, be determined by a function of either: (a) the physical address (PA) of the page 1; or (b) one or more bits within the first byte of user data (i.e. the host data sector) written to the page 1. Fig.31(a) illustrates the  
10 arrangement of data in the controller buffer 320 before the start of a sector write operation, the data being arranged as a first portion 322 of user data and a second portion 324 of Header data. Fig.31(b) shows the arrangement of the data in a  
15 FLASH memory page, following completion of the write operation in which the offset S is determined by one or more bits within the first byte of user data (option (b) above). The data is  
20 stored as a first portion 326 of the user data, followed by a second portion 328 of the user data, followed by the Header 1b and ECC 1c, followed by the third and final portion 330 of the  
25 user data. The length of portion 326 + portion 328 is dependent on data within portion 326. The length of portion 326 is defined to be less than or equal to the minimum offset, and the length of 328 is calculated on the basis of data  
30 within portion 326 to provide the correct Offset S. The first 20 and second portions 326, 328 of user data are separately identified so that the first portion 326 may be read from the FLASH memory by the controller in one operation, and evaluated  
35 by the controller in order to determine the length of the second portion 328 which should be read by the controller in a  
25 subsequent operation Fig.32 is a table detailing the sequence of controller commands used to transfer the data from the  
40 controller buffer to the FLASH memory during the write operation.

45 30 One advantage of choosing the offset S to be a function of one or more bits of the user data is that the overhead data is therefore not inserted at the same position in the 528Byte data segment in every sector. This protects the valuable  
50 overhead data from simultaneous loss on a large number of  
55

sectors in the event of a systematic failure in FLASH memory, such as a memory array column failure.

Fig.33 shows the resulting arrangement of data in the controller buffer after completion of a read operation on the FLASH memory page of Fig.31(b). From Fig.33 it will be seen that the data in the buffer is arranged back to a first portion 322 of user data and a second portion 324 of Header data, now followed by a third and final portion 325 of ECC. Fig.34 is a table detailing the sequence of controller commands used to transfer the data from the FLASH memory to the controller buffer during the read operation.

Additionally, with reference to interleaved write operations to multiple FLASH chips, as described already with reference to multiple FLASH chip memory systems, we also propose that this technique for writing substantially concurrently to a plurality of chips may also be used for writing data to a single memory chip in which the physical page size is a multiple of the size of a sector write by the controller e.g. each page of the memory is four times the size of a segment of (user + overhead) data written by the controller, where the controller writes data in uniformly sized segments.

It will further be appreciated that the invention is applicable not only to NAND-type memories but also to other types of memory, such as AND and NOR type memories. In the case of AND type FLASH memory, each page 1 of a block has the same format as the NAND page format of Fig.28 and we can use any of the possible arrangements of data within the pages as afore-described. We design the controller to still erase memory in blocks of sectors, although in blocks containing bad sectors the individual good sectors in the block to be erased will be erased individually. Thus, the controller does not treat any blocks containing bad sectors as bad blocks, but



5 instead treats them as good (erasable) blocks and makes use of  
the good sectors within those blocks. In AND type embodiments  
though we ensure that the controller only uses blocks  
10 containing all good sectors for SAT blocks or ASBs.

5

Where AND type FLASH memory is being used and the memory  
system is a multiple FLASH chip system utilizing interleaved  
15 chip write operations as described above, where any block of  
sectors (pages) in one of the virtual blocks contains a bad  
10 sector, the controller causes the write pointers to skip this  
sector and go to the next good sector in the block e.g. where  
20 c=chip and s=sector, if a burst of four sector writes is c3s5,  
c4s5, c1s6, c2s6 then if c1s6 is a bad sector the sequence  
becomes c3s5, c4s5, c2s6, c3s6. This is in contrast to  
25 15 embodiments based on NAND type memory, where if one block in a  
virtual block contains one or more bad sectors the controller  
treats that block as a bad block and treats the whole virtual  
block as a bad virtual block.

30 20 Where we use NOR type FLASH memory, our preferred embodiment  
is one in which we design the controller of the memory system  
to still read and write data structures to and from the FLASH  
35 memory in uniformly sized sectors, each sector being 528 Bytes  
wide. Fig.35 illustrates schematically three such sectors  
25 1,2,3 in a block 4' of NOR memory. Due to the fact that one  
row of memory in a NOR block is only 512 Bytes wide it will be  
40 appreciated that each of our sectors in NOR therefore fills  
one row and wraps round to fill a part of the next row.  
Nevertheless, it would be possible to define our sectors in  
45 30 NOR memory in a different manner, and we may choose to use  
sectors of smaller or larger size than 528 Bytes, and a block  
could even contain sectors of more than one size. The  
50 controller may arrange the data within each sector in any of  
the various different ways already described with reference to

5 NAND and AND type memory pages, each sector including user and overhead data.

10 It will be appreciated from the foregoing that the physical  
5 sectors of the memory system, whether the memory system is  
based on NAND, AND or NOR type memory arrays, need not have  
any particular relationship to the physical architecture of  
15 the memory array itself, for example a sector need not  
correspond to a row (page) of the array, and no physical  
10 feature need be present to identify the boundary between one  
sector and a neighbouring sector. A sector can be interpreted  
20 as a group of memory cells which are always treated by the  
controller as a unit. Different sectors need not be of the  
same size. Moreover, the physical structure of a sector has no  
25 dependence on data which might be stored in the sector. Also,  
embodiments are possible in which defective regions within a  
row (page) of memory cells are tolerated and are simply  
skipped over by the controller when writing to physical  
30 sectors.

20  
With reference to the SAT, while as above-described the SAT is  
preferably stored in one or more blocks of the memory array 6,  
35 it would alternatively be possible to provide in the memory  
system 10 a separate non-volatile memory which is accessible  
25 to the controller, in which separate memory the controller  
40 stores the SAT.

Finally, in a modified version of the above-described  
embodiment, instead of always using available erased blocks in  
45 30 ascending order of their physical addresses as above-  
described, the controller uses the erased blocks in another  
order. In this modified embodiment, the NEB list contains a  
50 chosen subset of all the currently available erased blocks,  
the first block address in the NEB list is the next erased  
35 block to be used, and this first block address is removed from

5 the NEB list when it has been allocated for data storage use.  
Any new erased block which is created (e.g. due to creation of  
obsolete data, following a delete command from the host) is  
10 added to the bottom of the NEB list. This continues for a  
5 period determined by the controller (which could be a  
predetermined number of sector write commands from the host,  
for example), at the end of which period the controller re-  
15 compiles the NEB list by replacing the entries in the NEB with  
a new subset of the currently available erased blocks.  
10 Conveniently, subsets of the whole set of all erased blocks  
may be used sequentially in order of ascending physical block  
20 addresses. This modified embodiment may have some advantage in  
reducing memory space requirements in connection with  
monitoring and storing the erased state of all blocks.

## Claims

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CLAIMS

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1. A memory system for connection to a host processor, the  
5 system comprising:

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a solid state memory having non-volatile memory sectors which  
are individually addressable and which are arranged in  
erasable blocks of sectors, each said sector having a physical  
address defining its physical position in the memory;

20

10 and a controller for writing data structures to and reading  
data structures from the memory, and for sorting the blocks of  
sectors into blocks which are treated as erased and blocks  
which are treated as not erased; wherein the controller  
includes:

25

15 means for translating logical addresses received from the host  
processor to physical addresses of said memory sectors in the  
memory;

30

a Write Pointer (WP) for pointing to the physical address of a  
sector to which data is to be written to from the host

35

20 processor, said Write Pointer (WP) being controlled by the  
controller to move in a predetermined order through the  
physical addresses of the memory sectors of any block which is  
treated as erased and, when the block has been filled, to move  
to another of the erased blocks;

40

25 wherein the controller is configured so that, when a sector  
write command is received from the host processor, the  
controller translates a logical address received from the host  
processor to a physical address to which data is written by  
allocating for said logical address that physical address to

45

30 which said Write Pointer (WP) is currently pointing, and

50

wherein the controller is configured to compile a Sector  
Allocation Table (SAT) of logical addresses with respective  
physical addresses which have been allocated therefor by the  
controller, and to update the SAT less frequently than memory

55

35 sectors are written to with data from the host processor.

5 2. A memory system according to claim 1, wherein said Write Pointer (WP) is controlled by the controller to move in a predetermined order through the blocks which are treated as  
10 erased.

5 3. A memory system according to claim 1 or claim 2, wherein the physical sector addresses in the SAT are ordered by  
15 logical sector address (LSA), whereby the Nth SAT entry contains the physical address of a sector to which data having  
10 logical address N has been written.

20 4. A memory system according to claim 3, wherein the controller is configured so that when a sector read command is received from the host processor the controller looks up a  
25 15 logical sector address (LSA) received from the host processor in the SAT in order to obtain the physical sector address which the controller previously allocated to said logical sector address.

30 5. A memory system according to any preceding claim, wherein the SAT is stored in at least one of said blocks of memory sectors in the solid state memory.  
35

6. A memory system according to claim 5, wherein the  
25 controller is configured to update the SAT by rewriting the SAT in whole blocks.  
40

7. A memory system according to claim 5 or claim 6, wherein there is provided at least one block (ASB) of sectors  
45 30 containing modified versions of individual sectors of a SAT block.

50 8. A memory system according to claim 7, wherein each sector in a said ASB block contains the physical address of the

sector of the SAT block which it updates, and the modified version of the said sector of the SAT block.

9. A memory system according to claim 7 or claim 8, wherein when all the sectors in a said ASB block are written to with modified versions of SAT sector(s), the respective SAT block is rewritten so as to include all the modified versions in the ASB block and the ASB block is erased.

10. A memory system according to any preceding claim, wherein the controller is configured to control the Write Pointer (WP) so as to move sequentially, in ascending numerical order of physical address, through the erased blocks, as each block is filled with data written thereto.

11. A memory system according to claim 10, wherein the control of the Write Pointer (WP) is cyclic in the sense that once the sectors in the highest block, according to physical address order, have been filled with data the WP is controlled by the controller to wrap around to the block of sectors having the numerically lowest physical block address out of all the blocks currently being treated by the controller as erased.

12. A memory system according to any of claims 1 to 9, wherein the controller is configured to control the Write Pointer (WP) to move non-sequentially, according to physical address order, through the erased blocks.

13. A memory system according to any of claims 1 to 12, wherein each said memory sector (1) is physically partitioned into a data area (300) and a spare area (302) and the controller is configured so as to write overhead data (OD) comprising header data and error correction code data (ECC) at a position in the sector which is offset from the start of the data area (300) of the sector and to write user data, received

5 from the host processor, in the space remaining in the sector,  
on either side of the overhead data (OD).

10 14. A memory system according to claim 13, wherein said  
5 overhead data (OD) is offset by an amount which is determined  
by at least one bit of the user data to be written to the  
sector.

15 15. A memory system according to any preceding claim, wherein  
10 the memory sectors in each said block of sectors are erasable  
together as a unit.

20 16. A memory system according to claim 16, wherein the memory  
sectors in each said block of sectors are also individually  
25 15 erasable.

30 17. A memory system according to any preceding claim, wherein  
the controller is configured to control erase operations on  
the memory so as to only erase whole blocks of memory sectors,  
20 and wherein a block of sectors is treated by the controller as  
an erased block if all the memory sectors therein are erased  
sectors.

35 18. A memory system according to claim 17, wherein if a block  
25 contains one or more bad sectors, the controller defines the  
whole block as being bad and treats that block as a not erased  
40 block, whereby no data will be written thereto.

45 19. A memory system according to claim 16, wherein if a block  
30 contains one or more bad sectors the controller treats that  
block as an erased block whereby the controller may still use  
good sectors in the block to store data, and wherein the  
50 memory system includes a table identifying bad sectors and the  
controller is configured to check whether the next sector  
35 address to which the Write Pointer (WP) is to be moved is the



5 address of a bad sector and, if it is the address of a bad  
sector, to control the Write Pointer to skip this bad sector  
and move to the next sector address according to the  
predetermined order in which the sectors are to be written to.

10 5

20. A memory system according to any preceding claim, wherein  
each block of sectors has a physical block address defining  
15 its physical position in the memory and the physical address  
of each said memory sector includes the physical block address  
10 of the block in which it is located, and wherein the  
controller is configured to compile a list of the physical  
20 block addresses of at least some of the blocks of sectors  
being treated as erased, listed in an order in which the WP is  
to move through the blocks, which list is used by the  
15 controller in order to quickly identify the next block of  
25 sectors to be written to, and the memory system further  
includes temporary memory means in which said list is stored  
by the controller.

30 21. A memory system according to any preceding claim, wherein  
the controller is configured so that, when a sector write  
command is received by the controller from the host processor  
35 which command renders obsolete data previously written to  
another sector, the controller stores in a temporary memory of  
25 the memory system the address of the sector containing the now  
obsolete data.

40 22. A memory system according to claim 21, wherein the  
controller is further configured so that if a sector delete  
45 30 command, generated by a user, is received from the host  
processor by the controller, the controller marks as obsolete  
the sector to be deleted and stores the address of the sector  
in said temporary memory.

5 23. A memory system according to claim 21 or claim 22, wherein  
the controller is configured so as to allow only a fixed  
predetermined number of blocks at any time, herein referred to  
as the Current Obsolete Blocks (COBs), to contain one or more  
10 5 sectors containing obsolete data which was written by the  
Write Pointer (WP), and so that when all the sectors in a said  
COB contain obsolete data, the said COB is immediately erased.

15 24. A memory system according to claim 23, wherein the  
10 controller is configured so that where a sector in a block  
other than a said COB is to contain obsolete data, the  
20 controller: relocates any data in valid (not obsolete) sectors  
in a said COB to another block and then erases the said COB;  
marks said sector in the said block other than a COB as  
15 obsolete; and designates said other block as a new COB.

25 25. A memory system according to claim 23 or claim 24, wherein  
said fixed predetermined number of COBs is one.

30 26. A memory system according to claim 24, wherein said block  
to which the controller relocates said valid data is the block  
in which the WP is currently located.

35 27. A memory system according to claim 24, wherein the memory  
25 system includes a further write pointer, herein referred to as  
the Relocation Pointer (RP), for pointing to the physical  
40 address of the sector to which said valid data is to be  
relocated, the RP always being in a different block of sectors  
to the Write Pointer (WP).

45 30 28. A memory system according to claim 27, wherein the memory  
system includes a further write pointer, referred to as the  
50 System Write Pointer (SWP), which points to the physical  
address of the sector to which system data is to be written

5 from the host, the SWP always being in a different block to the Write Pointer (WP).

10 29. A memory system according to claim 28, wherein the controller is configured so as to allow at least two blocks which contain one or more obsolete sectors to exist at any time, one being said COB and the other being a Current Obsolete System Block (COSB) containing one or more obsolete system data sectors and, if any system data sectors need to be  
15 20 relocated in order to allow the COSB to be erased, the relocated system data is sent to the address to which the System Write Pointer (SWP) is currently pointing.

25 30. A memory system according to claim 28, wherein the memory system includes another write pointer, herein referred to as the System Relocation Pointer (SRP), for pointing to the physical address of the sector to which valid system data is to be relocated, the SRP always being in a different block of  
30 sectors to the Write Pointer (WP) and the System Write Pointer (SWP).

35 31. A memory system according to any of claims 28 to 30, wherein the controller is configured so that if the COB contains one of said write pointers (WP, RP, SWP, SRP) at the  
40 45 time when the controller needs to erase a said COB because obsolete data has just been created in another block, the controller proceeds with creating a new COB but postpones the erasure of the old COB, herein referred to as the Pending Obsolete Block (POB), until all erased sectors in the POB have  
50 55 been filled and said Pointer moves on to the next erased block to be used, as defined by the controller, at which time any valid (not obsolete) data in the POB is relocated by the controller and the POB is erased.

5 32. A memory system according to claim 29, wherein the  
controller is configured to store in a temporary memory of the  
memory system respective lists of logical sector addresses  
10 corresponding to sectors in the memory to which relocated data  
5 has been written to by the RP (herein referred to as the  
Relocation Sector List or RSL), the SWP (herein referred to as  
the Write System Sector List or WSSL), and the SRP (herein  
15 referred to as the System Relocation Sector List or SRSL)  
since the SAT was last updated, and the controller is  
10 configured to store in said temporary memory corresponding  
lists of the order of blocks which have been used by the RP,  
20 SWP and SRP (herein referred to as the Relocation Block List  
(RBL), the Write System Block List (WSBL) and the System  
Relocation Block List (SRBL)).

15 33. A memory system according to any preceding claim, wherein  
25 in addition to writing data structures to the memory from the  
host processor, the controller also generates and writes to  
the memory data designated as control information, and the  
30 controller is configured so as to write such control  
information in one or more different ones (Control Blocks or  
CBs) of the blocks of memory sectors to those in which data  
35 structures received from the host processor are written.

25 34. A memory system according to claim 33, wherein the  
controller is configured to store in at least one said Control  
40 Block a list of the block addresses of all the SAT blocks.

35 35. A memory system according to claim 33 or claim 34, wherein  
45 the controller is configured to store the block addresses of  
said one or more Control Blocks in a dedicated block (the Boot  
Block or BB) of the memory, this dedicated block being the  
first block of sectors in the memory which does not contain  
50 any bad sectors.

35

5 36. A memory system according to claim 34, as dependent from  
claim 7, 8 or 9, wherein said list of all the SAT block  
addresses is in the form of a plurality of list portions  
10 (Table Block Lists or TBLs), and each said portion contains  
5 the block addresses of a group of logically contiguous SAT  
blocks and any ASBs corresponding thereto.

15 37. A memory system according to any of claims 7 to 9, wherein  
the controller is configured to store in a temporary memory of  
10 the memory system a list (the Write Sector List or WSL) of  
logical sector addresses for data structures which have been  
20 written by the Write Pointer (WP) since the SAT was last  
updated.

25 38. A memory system according to claim 37, wherein the  
controller is configured to also store in said temporary  
memory the order in which blocks have been used by the Write  
Pointer (WP) for writing data since the last update of the  
30 SAT, this order being stored in the form of a list (the Write  
20 Block List or WBL) of block addresses of the blocks in which  
the updated sectors whose addresses are held in the WSL are  
located.

35 39. A memory system according to claim 38, wherein the WSL has  
25 a predetermined size and once the WSL is full at least one SAT  
block or ASB block is updated and the WSL and WBL are emptied.

40 40. A memory system according to claim 38, wherein the  
controller stores a starting physical sector address, and the  
45 30 links between blocks containing sectors to which data has been  
written by the controller since the last update of a SAT or  
ASB block, in a said Control Block of the solid state memory.

50

55

5 41. A memory system according to any preceding claim, wherein each said sector consists of a single "page" of memory, namely one row of memory cells in a said block of memory sectors.

10 42. A memory system according to any preceding claim, wherein the controller is configured to write data to, and read data from, the memory sectors in uniformly sized data segments.

15 43. A memory system according to claim 42, wherein all the memory sectors are the same size and each said data segment is equal in size to the size of a said memory sector.

20 44. A memory system according to any preceding claim, further including a temporary cache memory in which the controller is configured to store a group of contiguous SAT entries including the SAT entry most recently accessed from the SAT by the controller.

25 45. A memory system according to claim 43, when dependent from claim 8, wherein the controller is configured to create in said temporary cache memory a list (ASBL) of physical addresses of all ASBs and the SAT blocks with which they are associated which is updated each time a SAT sector write operation is performed.

30 46. A memory system according to any preceding claim, wherein the solid state memory comprises a single memory array in the form of a single memory chip.

35 47. A memory system according to any of claims 1 to 45, wherein the solid state memory comprises a memory array formed by a plurality of memory chips.

40 48. A memory system according to any of claims 1 to 45, wherein the solid state memory comprises a plurality of memory

5 arrays in the form of a plurality of memory chips, and wherein  
the controller is configured to form the memory sectors in the  
plurality of memory chips into a multiplicity of virtual  
10 blocks, each said virtual block comprising one erasable block  
5 of memory sectors from each said memory chip, and to sort said  
virtual blocks into ones which are treated as erased and ones  
which are treated as not erased.

15 49. A memory system according to claim 48, wherein the  
10 controller is configured to compile a list of the virtual  
blocks treated as erased and store this in temporary memory in  
20 the memory system, and to control the Write Pointer (WP) to  
move from one chip to another for each consecutive sector  
write operation, starting at one sector in one erasable block  
25 15 of the virtual block and moving consecutively to one sector in  
each of the other erasable blocks in the virtual block until  
one sector has been written in each erasable block of the  
virtual block, and then moving back to the chip in which the  
30 first sector was written and proceeding in a similar manner to  
20 fill another one sector in each erasable block of the virtual  
block, and so on until the virtual block is full of data, and  
then to move the Write Pointer (WP) on to the next virtual  
35 block in said list of virtual blocks being treated as erased,  
and fill this next virtual block in a similar manner.

25 50. A memory system according to claim 49, wherein the  
40 controller is configured so that for every n contiguous sector  
write operations the controller executes for a multiple sector  
write command received from the host processor, where n is  
45 30 less than or equal to the number of solid state memory chips  
in the memory system, the controller writes substantially  
concurrently to one sector in each of n of the chips.

50 51. A memory system according to claim 49 or claim 50, wherein  
35 the controller is configured to carry out erasure of any said

5 virtual block by concurrently erasing all the erasable blocks  
in the virtual block.

10 52. A memory system for connection to a host processor, the  
5 memory system comprising:

a solid state memory comprising a plurality of solid state  
memory chips each having non-volatile memory sectors which are  
15 individually addressable and which are arranged in erasable  
blocks of sectors, each said sector having a physical address  
10 defining its physical position in the memory;  
and a controller for writing data structures to and reading  
20 data structures from the memory, wherein:  
the controller forms the erasable blocks into virtual blocks,  
each said virtual block comprising an erasable block from each  
25 of the memory chips, and the controller sorts the virtual  
blocks into ones which are treated as erased and ones which  
are treated as not erased, and the controller fills one  
virtual block with data prior to moving on to the next virtual  
30 block to be filled, and each virtual block is filled by  
20 writing to the memory sectors thereof in a repeating sequence  
in which the controller writes to one memory sector in each of  
the erasable blocks of the virtual block one after another  
35 whereby consecutively written sectors are in different chips.

25 53. A memory system according to claim 52, wherein the  
controller is configured so that for every n contiguous sector  
40 write operations the controller executes for a multiple sector  
write command from the host processor, where n is less than or  
equal to the number of solid state memory chips in the memory  
45 30 system, the controller writes substantially concurrently to  
one sector in each of n of the chips.

50 54. A controller for writing data structures to and reading  
data structures from a solid state memory having non-volatile  
35 memory sectors which are individually addressable and which



5 are arranged in erasable blocks of sectors, each said sector  
having a physical address defining its physical position in  
the memory, wherein the controller includes:  
means for translating logical addresses received from a host  
10 processor of a memory system in which the controller is used  
to physical addresses of said memory sectors in the memory,  
and for sorting the blocks of sectors into blocks which are  
treated as erased and blocks which are treated as not erased;  
15 and a Write Pointer (WP) for pointing to the physical address  
20 of a sector which is to be written to from the host processor,  
said Write Pointer (WP) being controlled by the controller to  
move in a predetermined order through the physical addresses  
of the memory sectors in any block which is treated as erased  
and, when the block has been filled, to move to another of the  
25 erased blocks, and wherein the controller is configured so  
that, when a sector write command is received by the  
controller from the host processor, the controller translates  
a logical sector address received from the host processor to a  
30 physical address to which data is written by allocating for  
said logical address that physical address to which said Write  
Pointer (WP) is currently pointing;  
and wherein the controller is configured to compile a table  
35 (the SAT) of logical addresses with respective physical  
addresses which have been allocated therefor by the  
controller, and to update the SAT less frequently than memory  
sectors are written to with data from the host processor.

55. A method of controlling reading and writing of data  
structures to and from a solid state memory having non-  
45 volatile memory sectors which are individually addressable and  
which are arranged in erasable blocks of sectors, each said  
sector having a physical address defining its physical  
position in the memory, the method comprising the steps of:  
50 sorting the blocks of sectors into blocks which are treated as  
erased and blocks which are treated as not erased;

5 providing a Write Pointer (WP) for pointing to the physical  
address of a sector which is to be written to, and controlling  
said at least one Write Pointer (WP) so as to move in a  
10 predetermined order through the physical addresses of the  
5 memory sectors of any block which is treated as erased, and  
when the block has been filled to move to another of the  
erased blocks and, when a sector write command is received  
15 from the host processor, translating a logical address  
received from the host processor to a physical address to  
10 which data is written by allocating for said logical address  
that physical address to which said Write Pointer (WP) is  
20 currently pointing;  
storing in non-volatile solid state memory a table (the SAT)  
of logical addresses with respective physical addresses which  
25 have been allocated therefor by the controller;  
and updating the SAT less frequently than memory sectors are  
written to with data from the host processor.

30 56. A memory system for connection to a host processor, the  
20 system comprising:  
a solid state memory having non-volatile memory sectors which  
are individually addressable and which are arranged in  
35 erasable blocks of sectors, each said sector having a physical  
address defining its physical position in the memory;  
25 and a controller for writing data structures to and reading  
data structures from the memory, wherein the controller  
40 includes means for translating logical addresses received from  
the host processor to physical addresses of said memory  
sectors in the memory; and wherein  
45 each said memory sector (1) is physically partitioned into a  
data area (300) and a spare area (302) and the controller is  
configured so as to write overhead data (OD) comprising header  
data and error correction code data (ECC) at a position in the  
50 sector which is offset from the start of the data area (300)  
35 of the sector and to write user data, received from the host

5 processor, in the space remaining in the sector, on either  
side of the overhead data (OD).

10 57. A memory system according to claim 56, wherein said  
s overhead data (OD) is offset by an amount which is determined  
by at least one bit of the user data to be written to the  
sector.

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1/21

Fig.1.

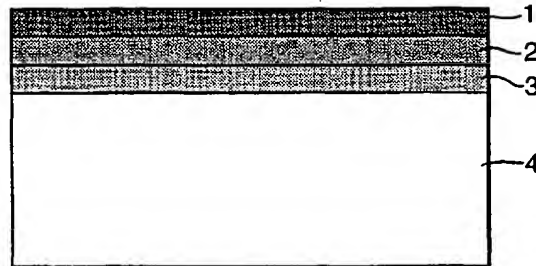


Fig.2.

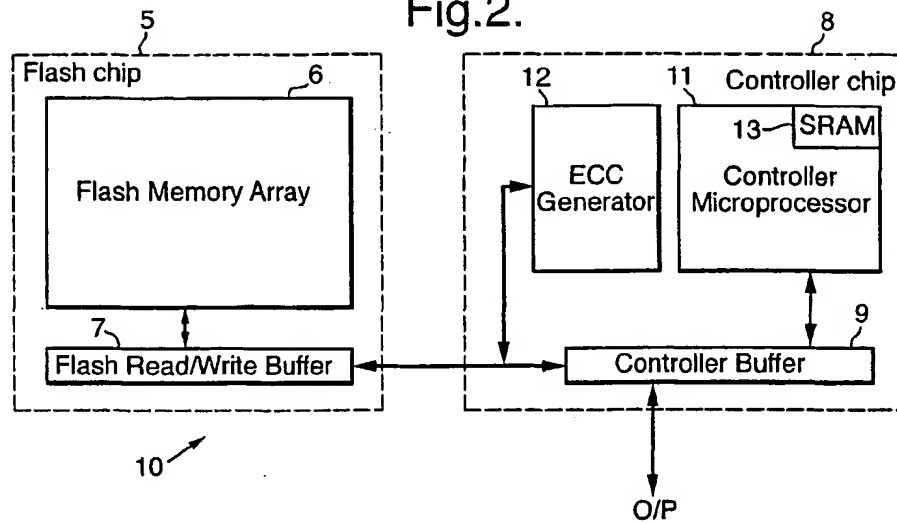


Fig.3.

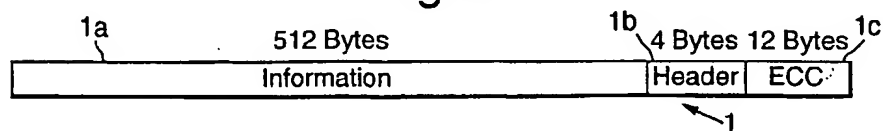


Fig.4.

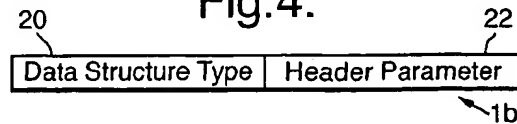


Fig.5.

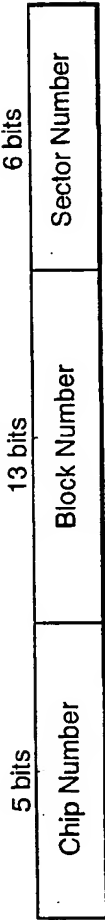


Fig.6.

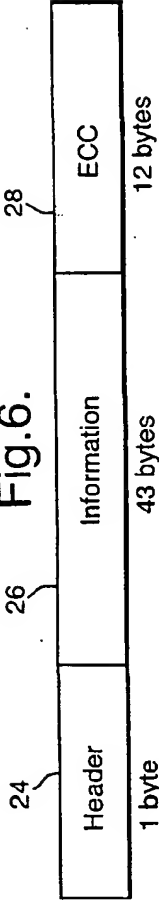


Fig.7.

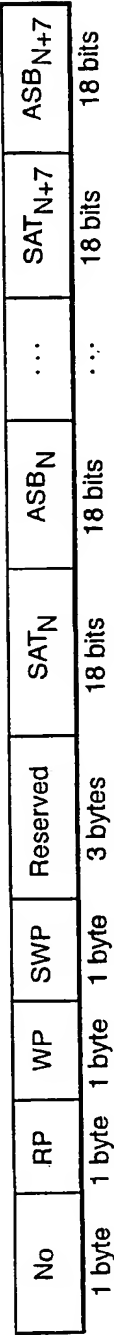


Fig.8.

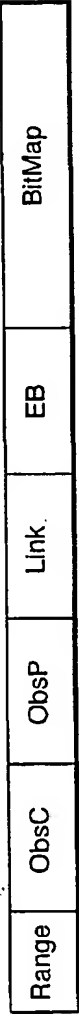


Fig.9.

SAT Block Index	SAT Block Address	ASB Address	LWP	NVP	ASB Page 0	...	ASB Page N
2 bytes	3 bytes	3 bytes	1 byte	1 byte	1 byte	...	1 byte

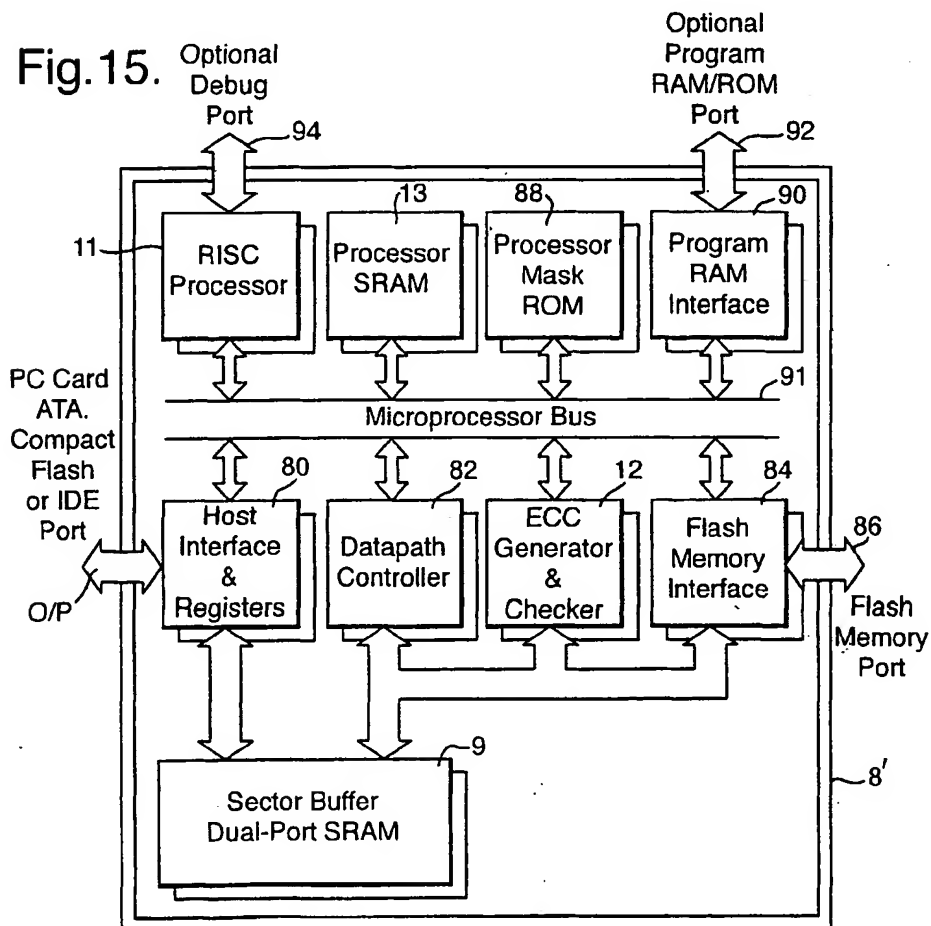
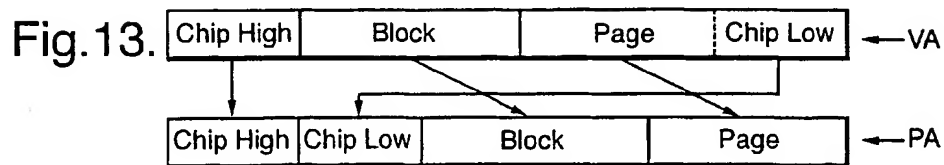
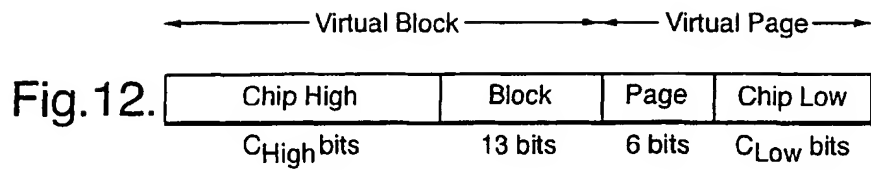
Fig.10.

28	Block Number	Obsolete or Deleted Sector Mask
	4 bytes	32 bytes

Fig.11.

Chip 0 Block 0	Chip 1 Block 0	Chip 2 Block 0	Chip 3 Block 0
0	1	2	3
4	5	6	Etc.

4/21



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5/21

Fig. 14.

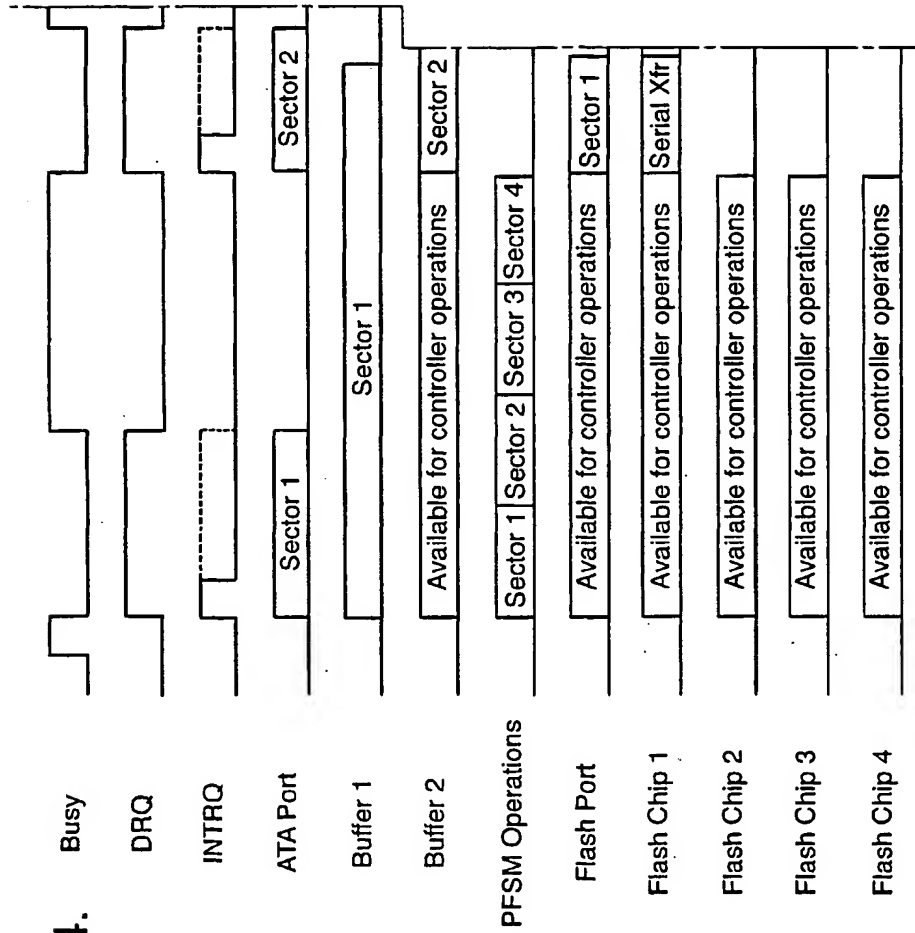
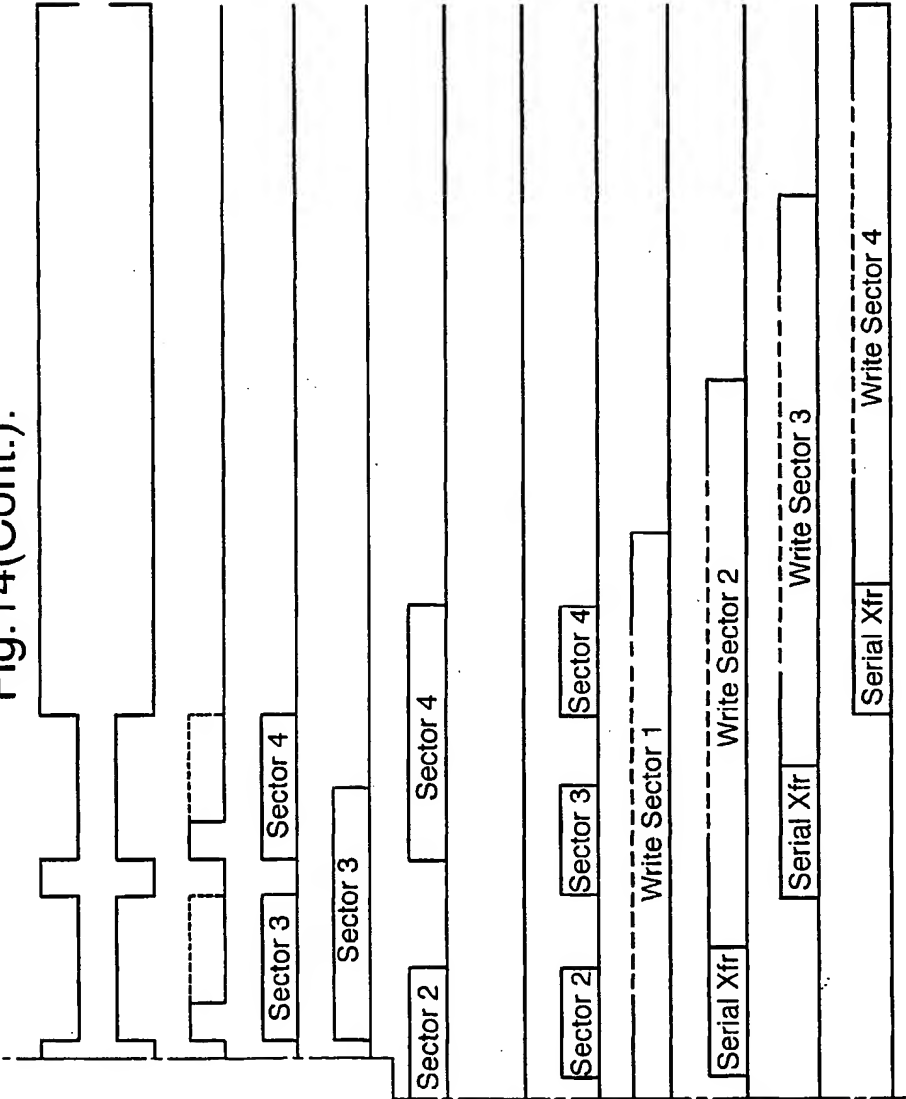




Fig. 14(Cont.).



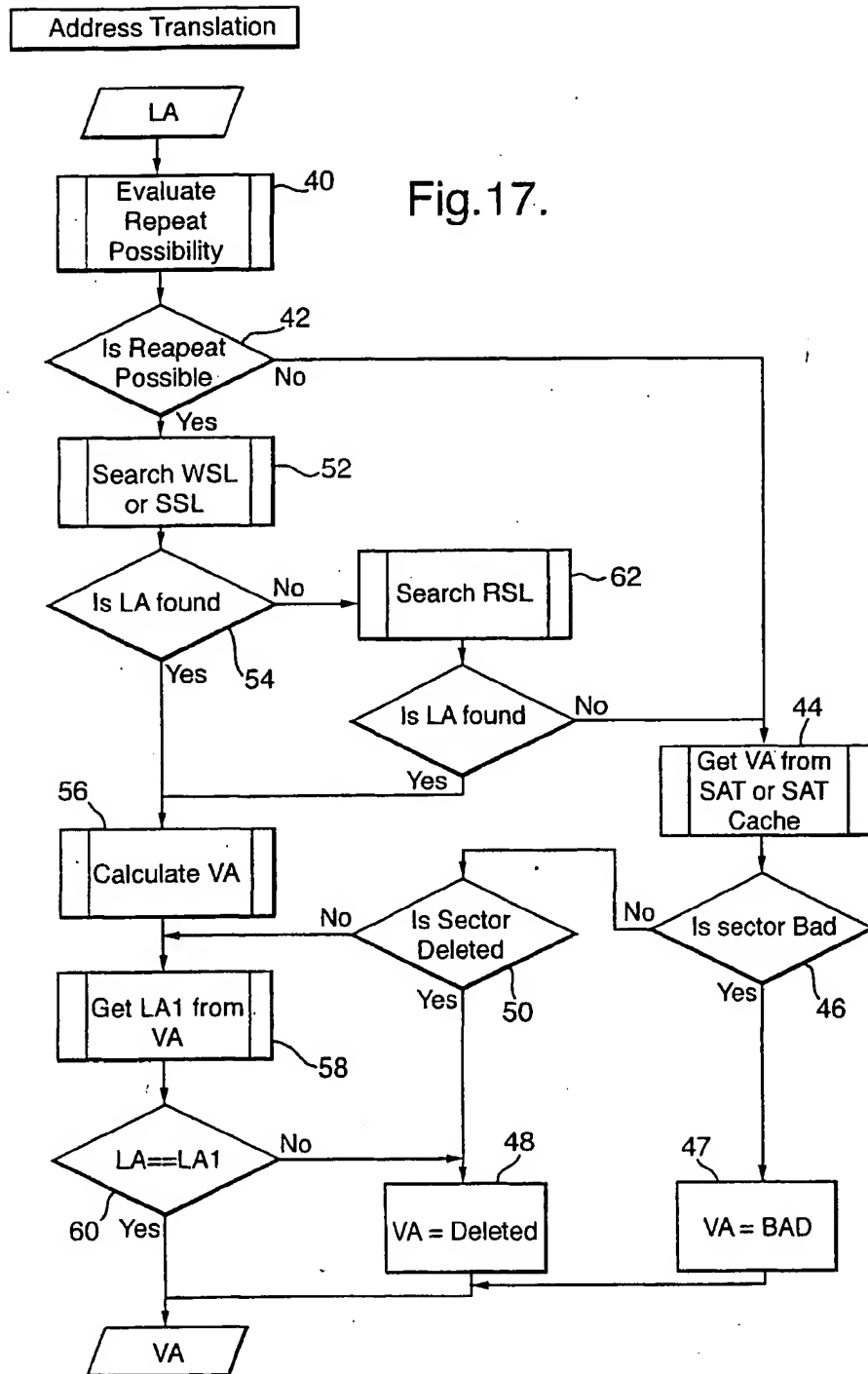
7/21

Capacity Allocation Table

	8MB Card		64MB Card		512MB Card	
	Number of Blocks	% of Capacity	Number of Blocks	% of Capacity	Number of Blocks	% of Capacity
Total Capacity	1024	100%	8192	100%	65536	100%
Sectors	1007	98.1%	8132	99.2%	65131	99.4%
Boot Block	1	0.1%	1	0.01%	1	0.00%
Control Block	3	0.3%	4	0.05%	4	0.00%
Sector Address Table	6	0.6%	48	0.6%	384	0.6%
Additional SAT Blocks	6	0.6%	8	0.1%	8	0.01%
Obsolete Sectors	1	0.1%	1	0.01%	1	0.00%
Erased Buffer	2	0.2%	2	0.02%	2	0.00%
Spare Blocks						

Fig.16.

8/21



9/21

Fig.18.

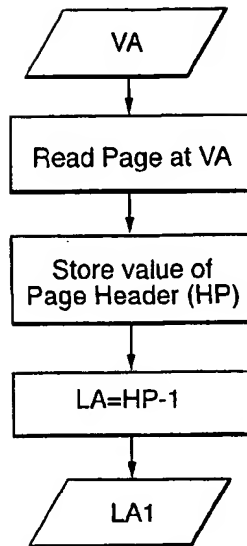
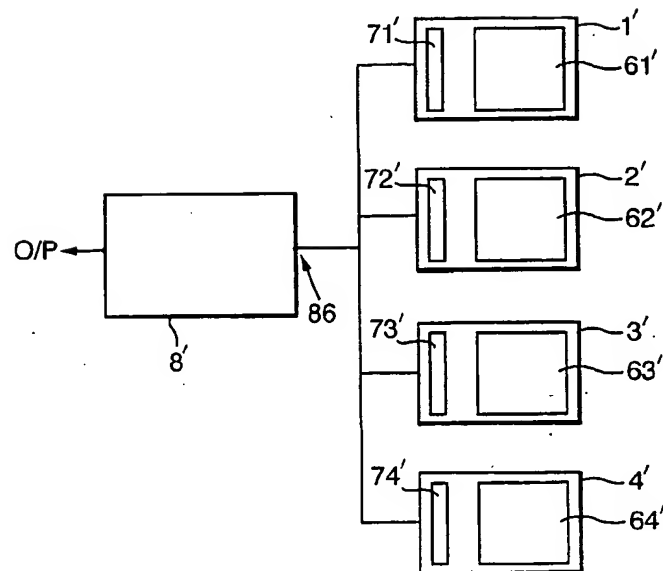
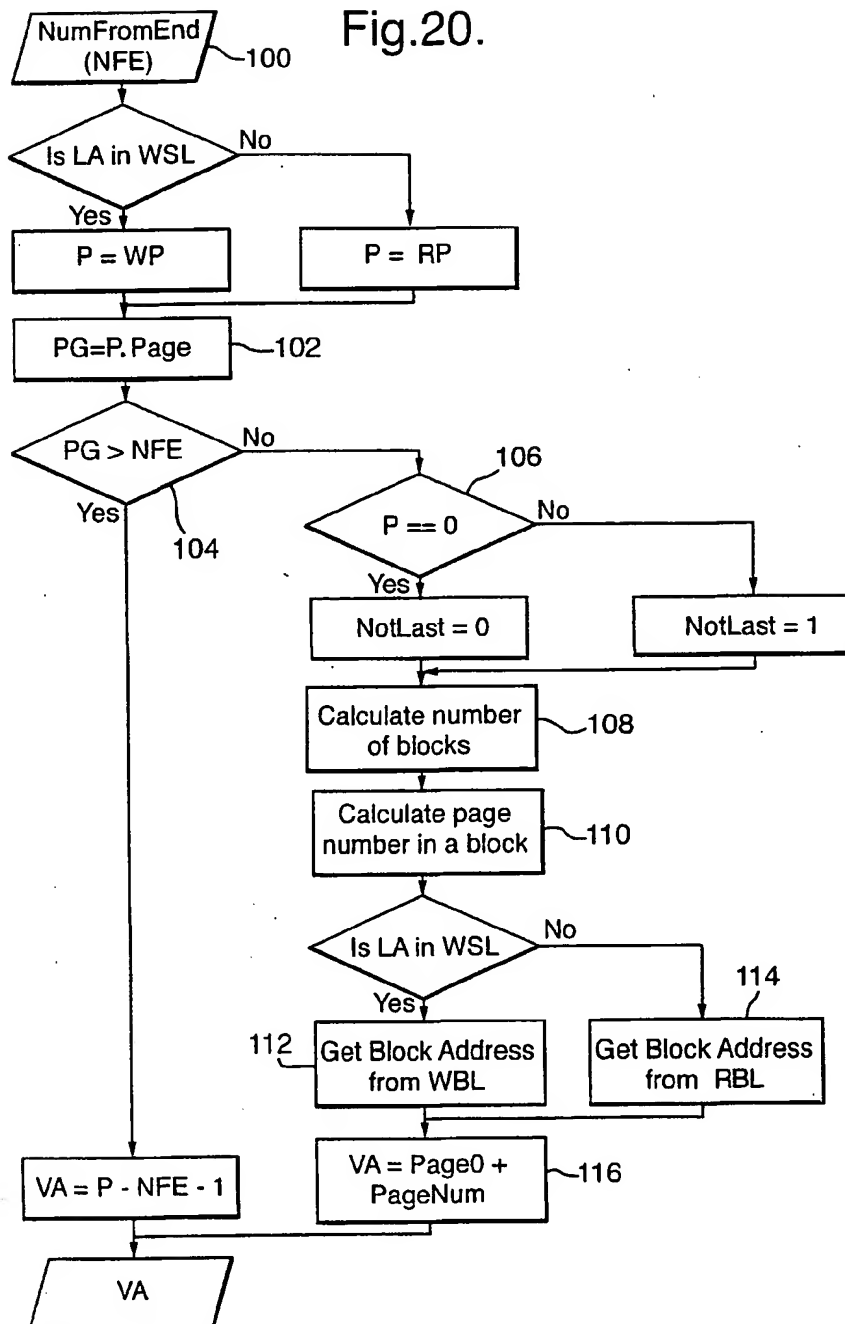


Fig.19.



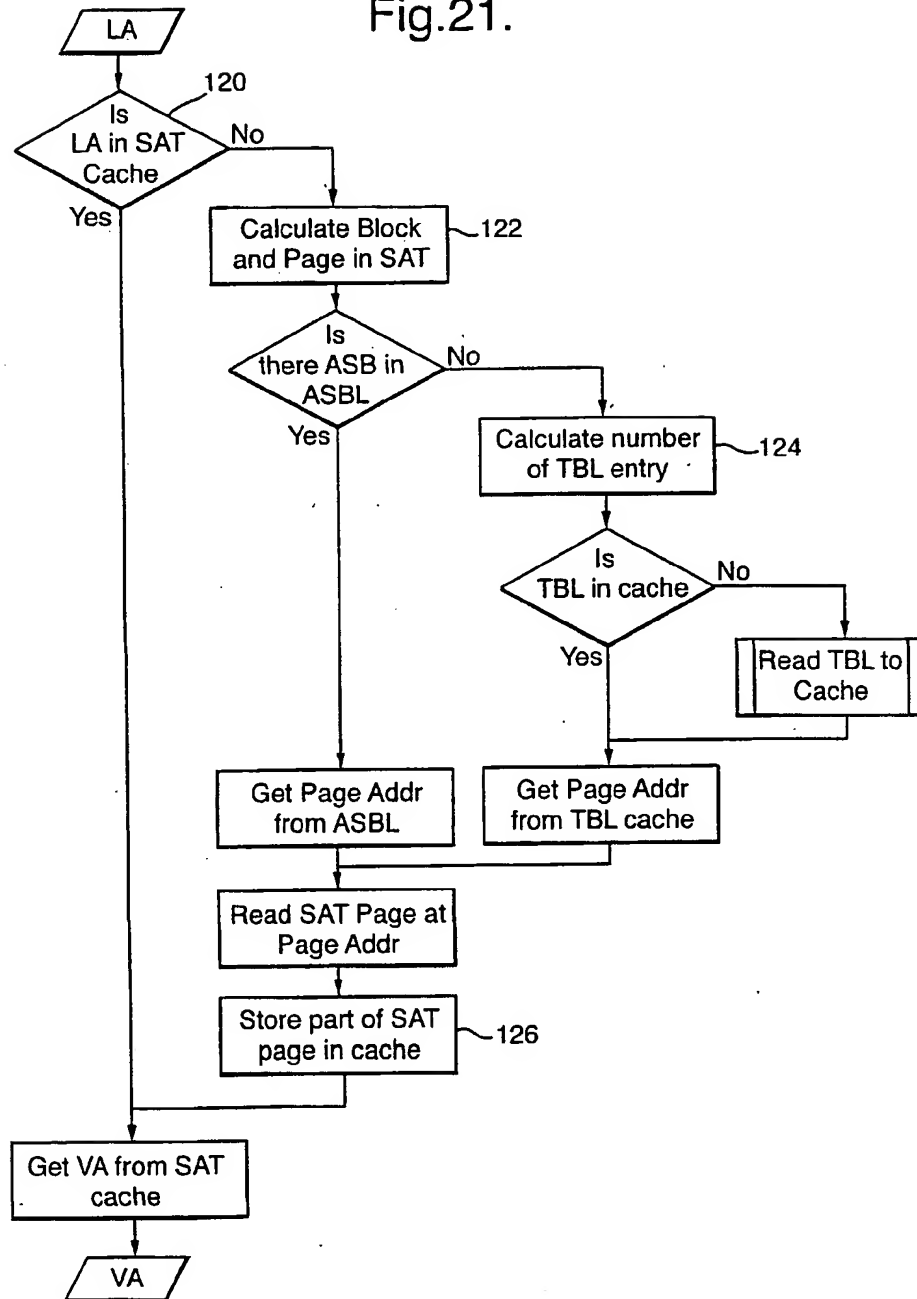
10/21

Fig.20.



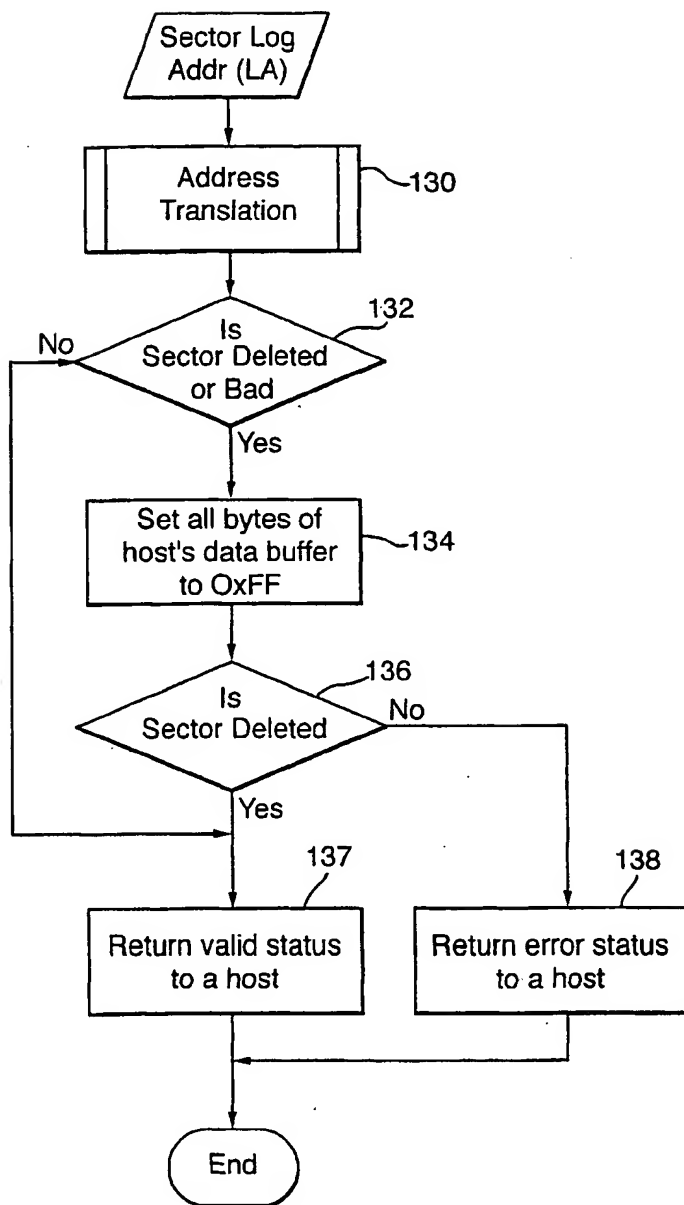
11/21

Fig.21.



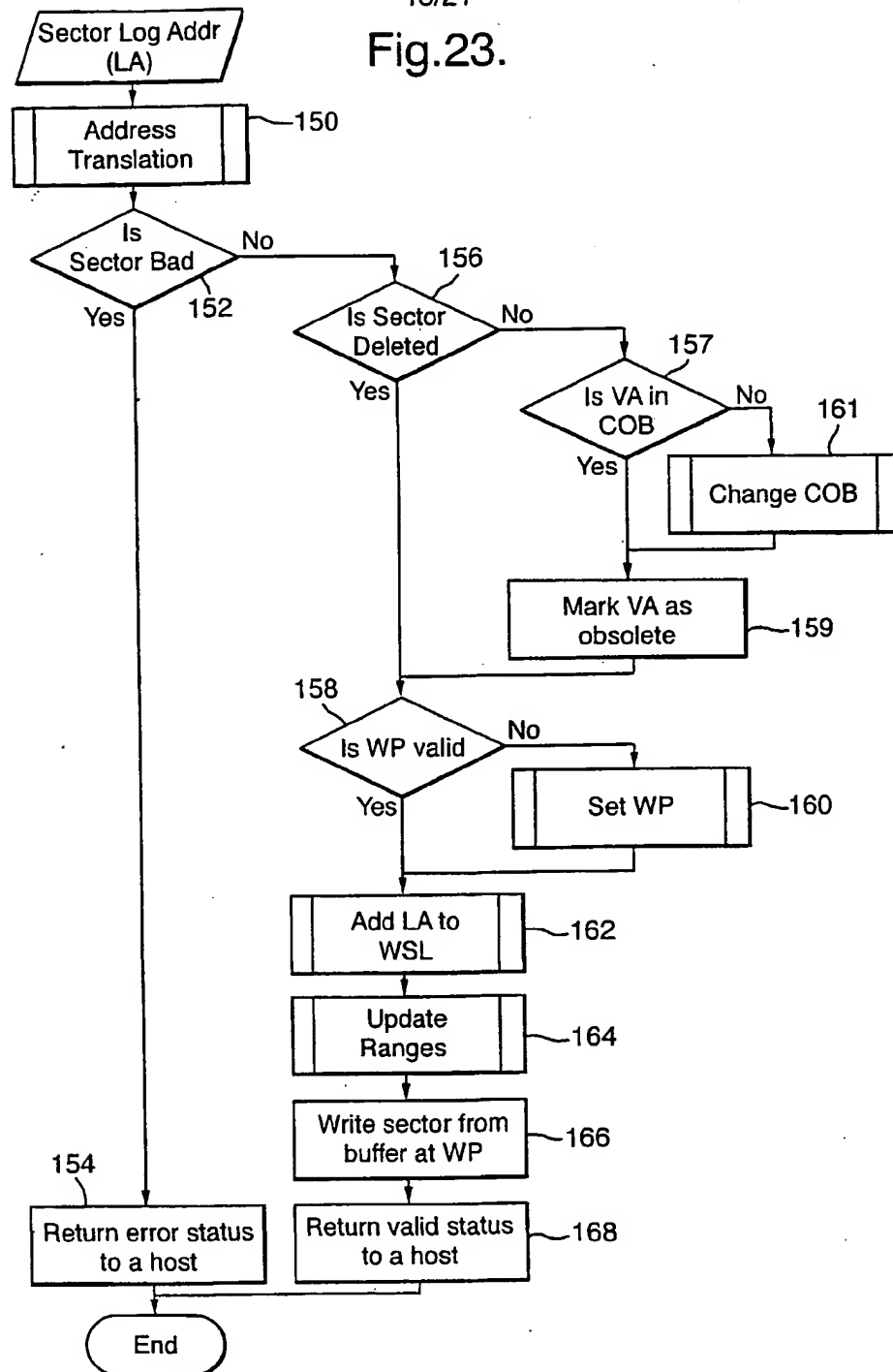
12/21

Fig.22.



13/21

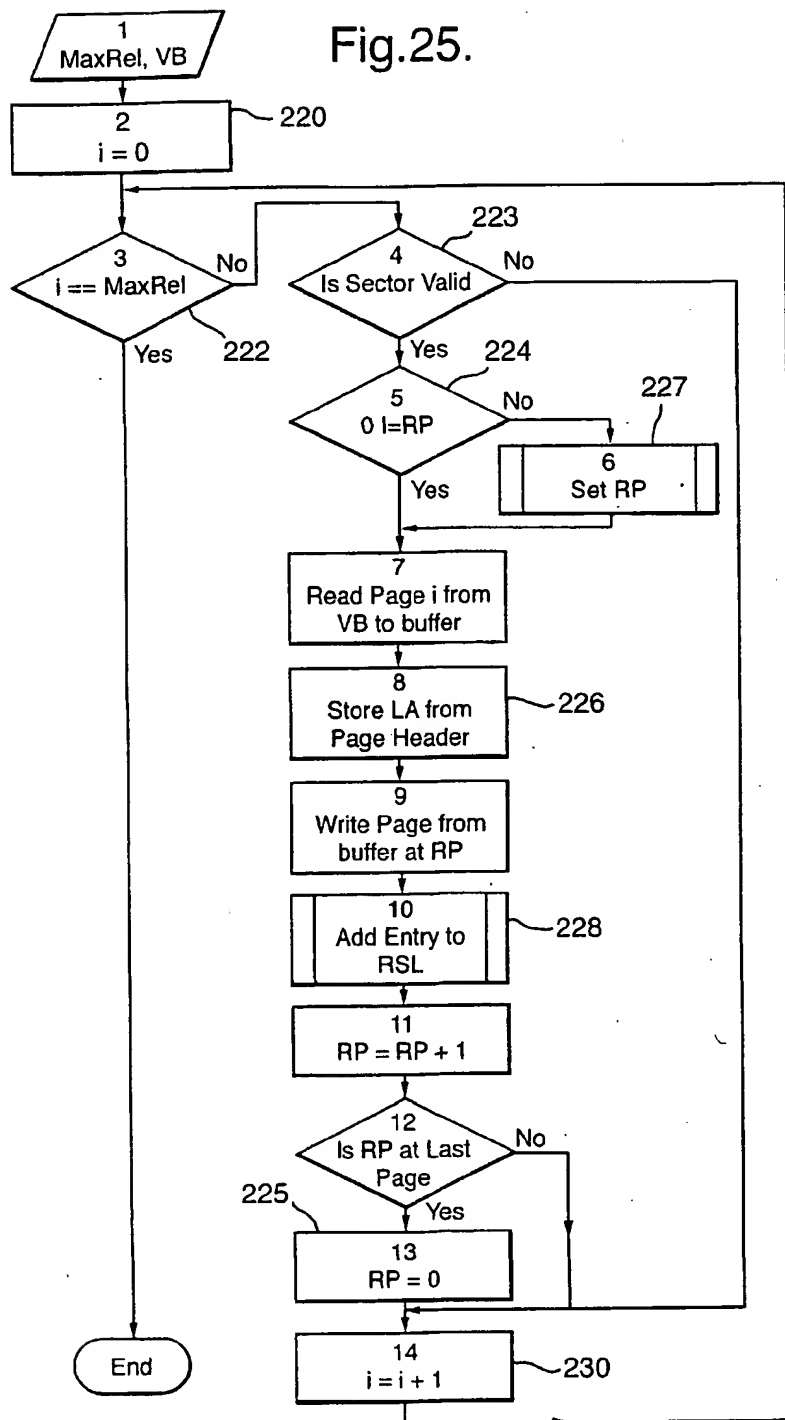
Fig.23.





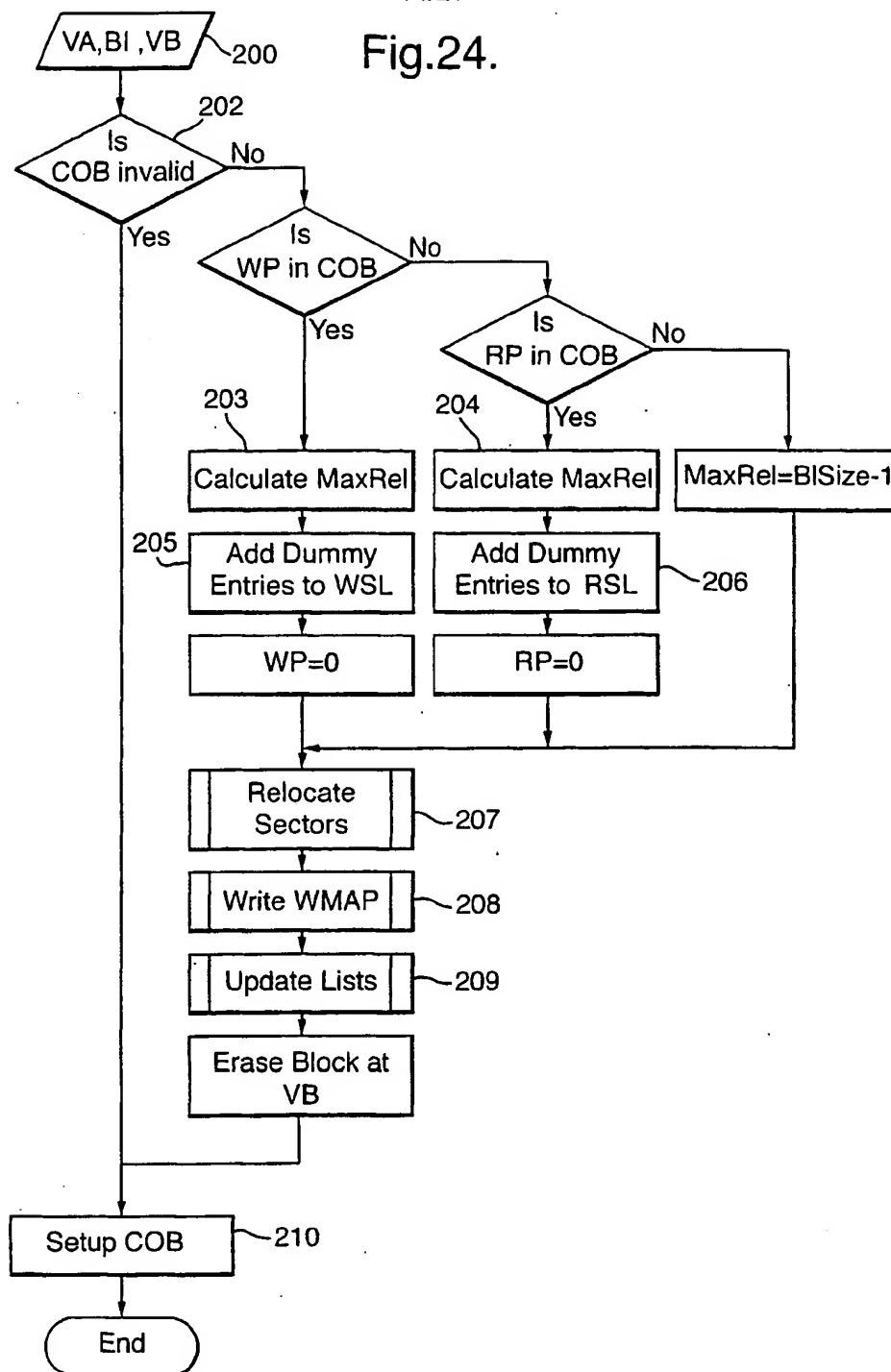
15/21

Fig.25.



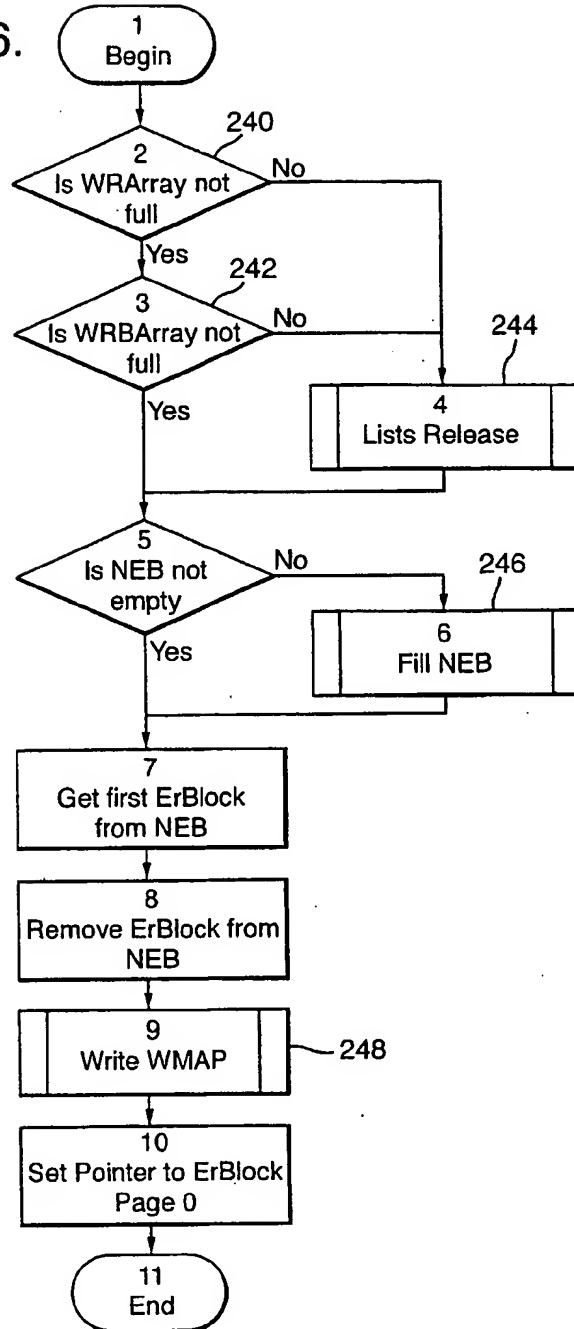
14/21

Fig.24.



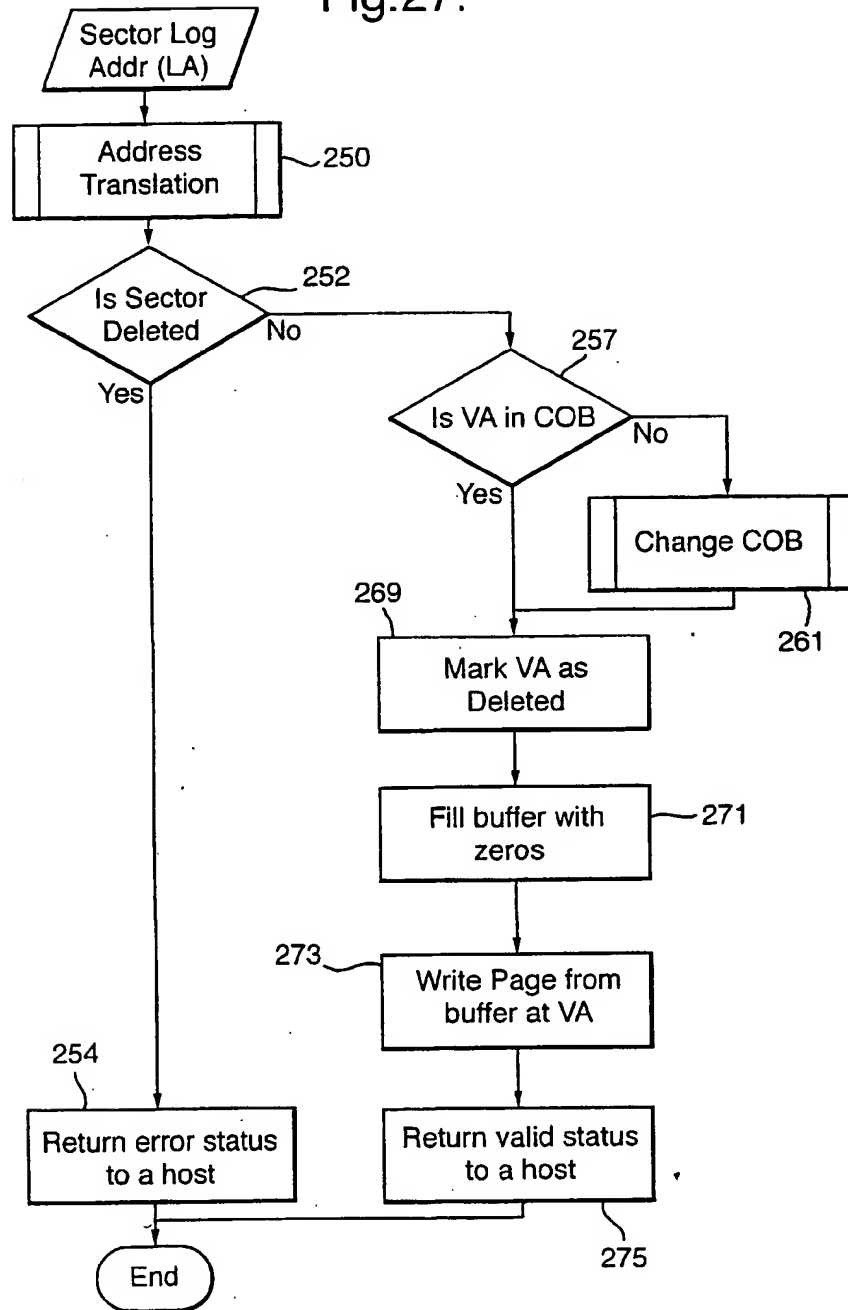
16/21

Fig.26.



17/21

Fig.27.



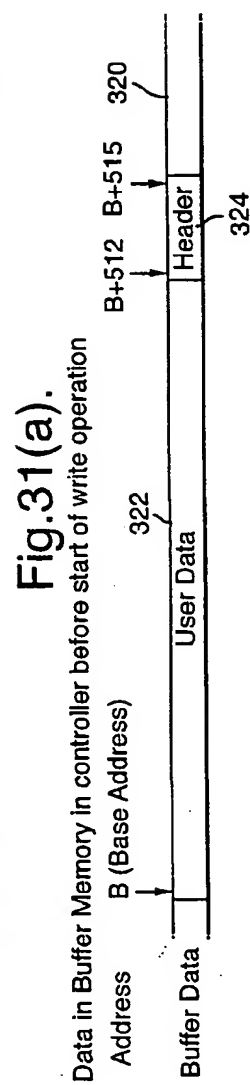
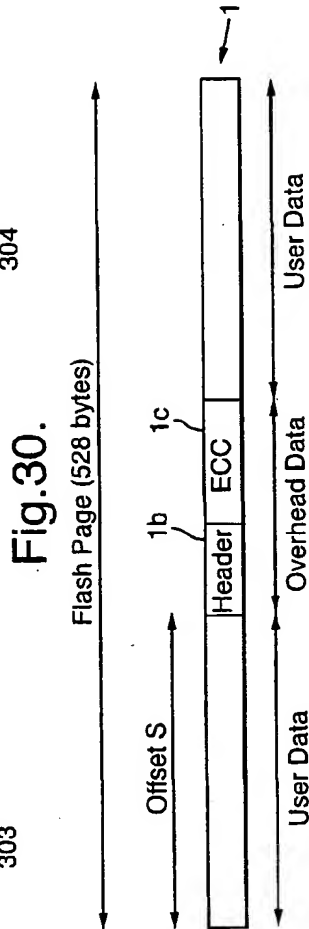
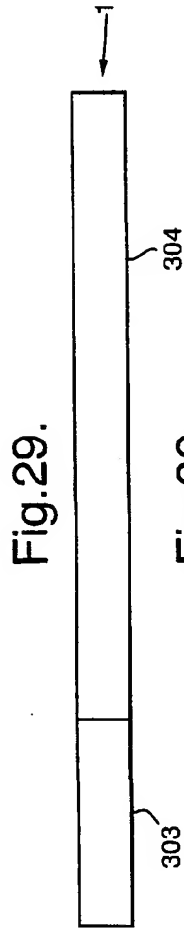
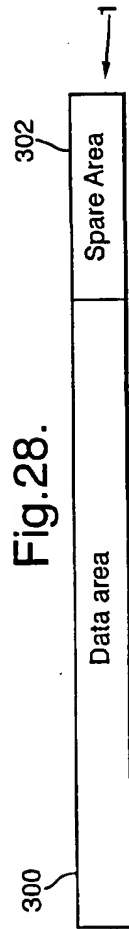


Fig.31(b).

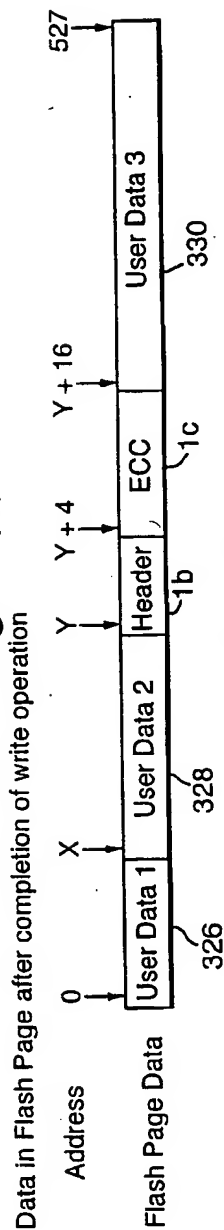


Fig.33.

Data in Buffer Memory in controller after completion of read operation

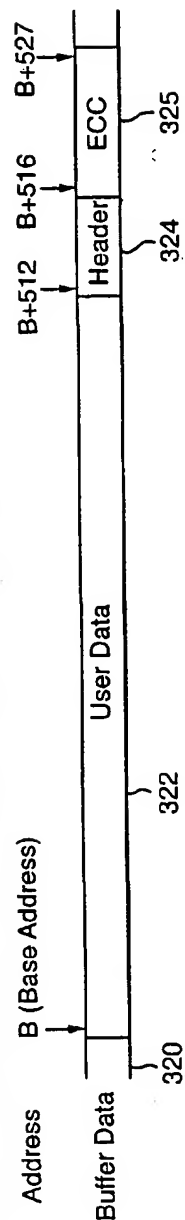
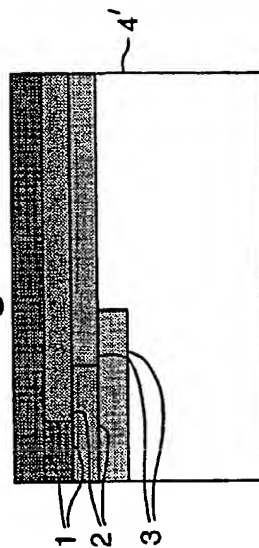


Fig.35.



20/21

**Fig.32.**  
Sequence of commands to controller data transfer hardware

Command Sequence	Command Parameters			Command Description		
	Flash Start Address	Buffer Start Address	No. of Data Xfr Cycles	ECC Generator Mode	Flash Clock	Summary
Cmnd 1	n/a	B	516	Generator on Output register disabled	off	Generate ECC for 512 bytes of User Data + Header
Cmnd 2	0	B	Y	Generator off Output register disabled	on	Transfer User Data 1 + User Data 2 to Flash buffer
Cmnd 3	continue	B + 512	4	Generator off Output register disabled	on	Transfer Header to Flash buffer
Cmnd 4	continue	n/a	12	Generator off Output register enabled	on	Transfer ECC to Flash buffer
Cmnd 5	continue	B + Y	512 - Y	Generator off Output register disabled	on	Transfer User Data 3 to Flash buffer Write Flash buffer to Flash array

Fig.34.

Sequence of commands to controller data transfer hardware

Command Sequence	Command Parameters			Command Description		
	Flash Start Address	Buffer Start Address	No. of Data Xfr Cycles	ECC Generator Mode	Flash Clock	Summary
Cmnd 1	0	B	X	Generator on Output register disabled	on	Read Flash page to Flash buffer Transfer User Data 1 from Flash buffer
Cmnd 2	continue	B + X	Y - X	Generator on Output register disabled	on	Transfer User Data 2 from Flash buffer
Cmnd 3	continue	B + 512	16	Generator off Output register disabled	on	Transfer Header + ECC from Flash buffer
Cmnd 4	continue	B + Y	512 - Y	Generator on Output register disabled	on	Transfer User Data 3 to Flash buffer
Cmnd 5	n/a	B + 512	16	Generator on Output register disabled	off	Transfer Header + ECC from Buffer to ECC Generator



# INTERNATIONAL SEARCH REPORT

International Application No.

PCT/GB 00/00550

## A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 G06F3/06

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 G06F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	GB 2 291 991 A (MEMORY CORP PLC) 7 February 1996 (1996-02-07)	1,2,4, 10,11, 15,17, 20,46, 47,52, 54-56
A	page 5, line 15 -page 8, line 5; figures WO 97 37296 A (SINCLAIR ALAN WELSH ;MEMORY CORP PLC (GB)) 9 October 1997 (1997-10-09) page 3, line 21 -page 7, line 6; figures -/--	1,52, 54-56

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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# INTERNATIONAL SEARCH REPORT

International Application No  
PCT/GB 00/00550

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
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